Article 13 Report

Maize and Biodiversity: The Effects of Transgenic Maize in Mexico

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Chapter 1 Context and Background on Wild and Cultivated Maize in Mexico

Antonio Turrent

1 Domestication of maize (where, when, who, how) and early development as a crop (genealogical relationships with wild relatives, co-evolution with teosinte, early races of maize)

2 Maize in pre-Columbian Mesoamerica: (a) modern races, (b) cultural implications: food, religion, social status, art, politics, war; (c) production technology, grain conservation technology, maize breeding strategy

Table: Nixtamalization, human nutrition, pellagra, a balanced diet

3 Dispersion of maize throughout the ancient world

Table: Maize as the second-largest cultivated crop in the world

4 Present-day distribution of cultivated maize and wild relatives in Mexico (maps, agricultural regions, modern varieties, local races, teosintes, cropping systems).

Table: Genomes of maize and teosinte, interbreeding, introgression,

Table: Maize breeding strategies of farmers; local markets as sources of new germplasm, seed color as a flag for managing sympatric maize resources

5 Mexico's farm sector and government action (affecting the basic resources of farmland, water availability, and genetic resources; land tenure, agro-climatic regions, farm typology, evolution of rural population, migration to urban areas and the diaspora; post-NAFTA small farm crisis)

6 Maize as a basic crop in Mexico (farmland in maize production and trade, population growth, research and liberation of modern hybrids and open pollinated varieties, potential production of maize, food security)

Table: The national research system, human resources and infrastructure

7 Erosion of maize germplasm and that of its wild relatives: (a) new and more productive hybrids displace maize land races; (b) migration; (c) change in land use reduces wild relatives ecosystems; (d) teosintes are considered weeds in modern cropping systems; (d) can this erosion be stopped?

Table: Status of *in situ* and *ex situ* germplasm conservation efforts of maize and teosinte

8 Presence of transgenic maize in Mexico: how it arrived; hybridization of nontransgenic maize land races

Table: Transgenic maize: what it is; recombinant ADN technology; state of knowledge, outlook, list of liberated transgenic maize, list of new TG maize in the testing stage, new developments

9 What is at stake?

Chapter 2 Identification of Potential Benefits and Risks

Paul Thompson

1 Problem identification

2 Elements of risk assessment
- 2.1 Hazard identification
- 2.2 Risk quantification and exposure estimation
- 2.3 Risk communication
- 2.4 Risk management

3 Environmental risks and GMOs
- 3.1 Environmental hazards
  - 3.1.1 Loss of or reduced ecosystem functioning
  - 3.1.2 Decreased biodiversity, including genetic diversity
- 3.2 Mechanisms for exposure to environmental hazards
  - 3.2.1 Intentional release of the transgenic organism (i.e., toxicity, bioaccumulation)
  - 3.2.2 Invasive, volunteer transgenic organisms (leading to displacement of a species or community, or exposure to a hazard if there is toxicity)
  - 3.2.3 Introgression of transgenes into feral populations or wild relatives (leading to displacement of a species or community, exposure to a hazard if there is toxicity, decreases in genetic diversity)

4 Public health risks
- 3.1 Food safety
- 3.2 Veterinary health

5 Socio-economic risks
- 4.1 Farmer production risks—economic losses, crop failure risks,
- 4.2 Consumer confidence risks
- 4.3 Market access risks (associated with trade, for example)
- 4.4 Risks to social capital and cultural identity

6 Issues in governance with respect to risk
- 5.1 Risk assessment as decision support
- 5.2 Risk benefit optimization versus informed consent

7 Risk management and public participation

Chapter 3 Assessment of Effects on Genetic Diversity

Julien Berthaud and Paul Gepts

Chapter 3 & 4 are closely interrelated.
Chapter 3 is about genetics and rates of change. Chapter 4 deals with populations.

Questions:

1 What levels of gene flow occur in maize and teosinte populations in Mexico?
2 To what extent do the recipient populations assimilate and retain these genes?
3 Demographic swamping: to what extent the gene flow will affect the nature of the populations permanently?
4 Single versus multiple transgenes, existing versus future transgenes: effects on populations

Outline:

1 Description of land races of maize and of species and subspecies of teosinte; assessment of current status of these land races, species, and subspecies
2 Kaleidoscopic evolving nature of these populations over time in Mexico; genetic and agronomic factors in their maintenance
3 Role of hybridization and introgression in the process, past, present, and future
4 What is the effect of introducing transgenes into these dynamics?
5 Briefly review evidence of transgenes
6 Future of this evolving system in Mexico; consequences of the introduction of transgenes into it
7 Means for the preservation of the genetic diversity of maize land races and teosinte taxa and of the processes that allowed for that diversity: what do we do about it?
8 In the context of deteriorating diversity in Mexico (agricultural, etc.), and of the migration of farmers to the United States and to major cities, what should be done, and how do transgenes add to or slow down this process?

Chapter 4 Assessment of Effects on Natural Ecosystems

L. LaReesa Wolfenbarger and Mario González-Espinosa

1 State of knowledge on effects of Bt crops on natural ecosystems

1.1 Introduction to the context: natural ecosystems in Mexico, their scientific significance and their value to humans

1.1.1 Historical perspective (generally and in Mexico)

State of the knowledge concerning the effects of agriculture on natural ecosystems, for instance, the effect from generating potential weeds on the biodiversity in nearby ecosystems? Enhancing or limiting natural populations of pollinators, birds, and other elements of biodiversity? Encouraging the spread of plant pests and diseases, or discouraging them? How have the effects of agriculture on the individual, a population and/or an ecosystem been identified? What reference points are used to evaluate impacts? What designs have been used to study effects on natural ecosystems? What results have been obtained? What reference or context has been used and how general are the conclusions from the studies?

2 State of knowledge on effects of Bt crops on natural ecosystems

2.1 A brief background on Bt toxin and its mechanism:

2.1.1 Source of genes
2.1.2 Variation in toxin specificity
2.1.3 Mode of action within insects
2.1.4 Insects have variable response
2.1.5 Lack of effects on vertebrates
2.1.6 Use of Bt sprays in agriculture

2.2 Hypotheses for transgenic crop effects on natural ecosystems with special emphasis on Bt maize

2.2.1 Causal effects on individuals (e.g., direct effects of Bt toxin)

- Direct mortality from ingesting Bt toxin (from transgenic plant, transgenic pollen, accumulated Bt toxin in soil)
- Direct sublethal effects from ingesting Bt toxin (from transgenic plant, transgenic pollen, accumulated Bt toxin in soil)
- Indirect mortality from prey items that have ingested Bt maize or Bt pollen (e.g., bioaccumulation)
- Indirect sublethal effects from prey items that have ingested Bt maize or Bt pollen

2.2.2 Causal effects on populations

- Variability in sensitivity to Bt toxin among individuals decreases genetic variation within populations or metapopulations
- Low natural rates of intrinsic growth lead to small or inviable population sizes

2.2.3 Causal effects on ecosystems

- Species susceptible to Bt toxin provide critical role for ecosystem dynamics (keystone predators, host specificity, guild)
- Species susceptible to Bt toxin provide ecosystem services (pollination, degradation, competitive exclusion maintaining diversity)
- Species susceptible to Bt toxin are rare or have small populations at higher risk of extinction from small perturbations

2.3 Hypotheses for effects of transgenic crops on natural ecosystems via changes in agricultural practices

2.3.1 Change in patterns of pesticide use (pre-emergent versus post emergent applications or number of applications)

- Effects on individuals
- Effects on populations
- Effects on ecosystems

2.3.2 Decrease in use of broad spectrum insecticides

- Effects on individuals
- Effects on populations
- Effects on ecosystems

2.3.3 Increase in non-target pest populations may continue use of insecticides

- Effects on individuals
- Effects on populations
- Effects on ecosystems

2.3.4 Change in field sizes

- Loss of marginal habitat or natural habitat if field sizes increase
- Increased fragmentation?
- Decreased pressure on land conversion to agriculture
- Effects on individuals
- Effects on populations
- Effects on ecosystems

2.3.5 Change in tillage practices

- Effects on individuals
- Effects on populations
- Effects on ecosystems

2.4 How would these hypotheses apply to introduction of Bt maize in Mexico?

2.4.1 Effects on insects: lepidopteran biodiversity in Mexico, insect diversity in general, importance of lepidopteran/insects on ecosystems in Mexico

2.4.2 Consequences of gene flow: In what habitats do maize and wild relatives co-exist? What role do wild relatives of maize have in contributing to their respective ecosystems (e.g., host plants for herbivores, habitat for animals, competitive interactions with other plant species, etc.)

2.4.3 What other agro-ecosystems that contribute to Mexican biodiversity co-exist with maize (i.e., coffee?) and with what effect from Bt crops

2.5 How specific is each hypothesis to Bt or transgenic crops in Mexico? And how might Bt or transgenic crops alter any existing trends in ecological impacts from agriculture (i.e., consider possible acceleration of negative effects and contributions to the preservation of ecosystems by the improvements of agricultural biotechnology)

2.6 Empirical work addressing these hypotheses

2.6.1 Summary of work

2.6.2 Strengths and limitations of empirical work relative to evaluating effects on natural ecosystems

- Direct toxicity or sublethal effects versus indirect ecological effects
- Laboratory versus field
- Single species versus community
- Temporal variation
- Spatial variation
- Variation in scale

2.6.3 Summary of known and unknown impacts

What is the answer to the question, "Will the introduction of transgenes have a positive or negative effect on natural ecosystems?"

3 Areas in which there are unresolved and/or controversial issues

3.1 Scientific controversies

3.1.1 What indicator species should be used?

3.1.2 What ecological interactions should be studied?

3.1.3 Community-level impacts: few species tested, species variability in sensitivity documented; therefore, difficult to predict impacts at a community level from few species studied

3.1.4 Significance of tri-trophic effects

3.1.5 Effects of scale

3.1.6 Cumulative ecological effects

3.1.7 What ecological impacts will changes in biodiversity have on ecosystems? Summary of work on ecosystem properties and biodiversity versus resiliency/redundancy of ecosystems

3.1.8 What baselines give information about ecological impacts? What scientific information/interpretation on ecological impacts can result from comparisons to conventional isolines, conventional varieties in general, alternative agricultural practices, natural ecosystems?

3.2 Policy controversies

3.2.1 What value is assigned to impacts and to uncertainty?

3.2.2 What is an appropriate baseline for comparison? What policy information/interpretation of ecological impacts can result from comparisons to conventional isolines, conventional varieties in general, alternative agricultural practices, natural ecosystems?

4 A list of priority topics where more research is needed to improve our understanding of the issues being addressed

(Possible resources to use in addition to our own synthesis: stakeholder workshop on biotechnology research priorities documents, NRC reports)

4.1 General priorities

4.2 How these apply to Mexico

5 Preliminary recommendations to CEC to address the issues

Possible figures and tables

1. Comprehensive summary of empirical work on effects of Bt maize
2. Map of maize-producing regions with overlap of ecosystem/habitat types in Mexico
3. Pathway diagram of hypotheses for ecological relationship that Bt maize may impact, highlight relationships where work has been conducted (reference Table 1)

Chapter 5 Assesment of Biological Effects in Agriculture

Major Goodman and Luis Enrique García Barrios

1 Ecological sustainability of the many and contrasting maize production systems practiced in Mexico

1.1 The diversity of maize agroecosystems in Mexico (environments, land-use intensities, companion crops, biodiversity, input-levels, operational scales, seed source choices, yield stability, management problems).

1.2 The evolving ecological adaptation of local landraces to the diverse, uncertain and resource-limited conditions of small-holder maize production systems. Do land races help cope with environmental and input restrictions?

1.3 Given the current socio-economic restrictions faced by maize producers in Mexico:

Can maize agroecosystems persist if they are subjected to further limitations (e.g., reduced prices, soil loss/deterioration; reduced biodiversity, increased pest problems/costs)?

2 Traits induced in the maize plant through trangenes. Present status and future prospects

2.1 Bt toxins

2.2 Herbicide resistance

2.3 Virus resistance

2.4 Male sterility

2.5 Drought resistance

2.6 Pharmaceutical drug production

2.7 Industrial chemical production

2.8 Other potential traits

3 Potential impacts of TGM in Mexican maize agroecosystems

Can current and potential transgene traits disrupt the structure and function of maize agroecosystems in Mexico? Can they solve or mitigate some of the most pressing ecological problems faced by Mexican maize producers? Evidence and conjectures derived from research in other countries in TGM fields and with other TG crops.

3.1 Expected positive ecological effects

- Reduced insecticide use
- Reduced pre-emergent herbicide use/environmentally friendlier herbicides
- Resistance to some viral diseases
- Reduced tillage and lessened soil erosion

- Drought tolerance
- Improved disease resistance through Marker-assisted Selection
- Others (oil, starch, yield, amino acid/protein, coloration, etc. modifications; heat/cold tolerance; maturity; metabolism, DNA/RNA syntheses changes, etc.)

3.2 Possible negative effects on the maize agroecosystem

- Insects can develop resistance to Bt maize, and to Bt spores used in some organic farming
- Development of wild relatives into weeds can be dramatically enhanced through flow of herbicide-resistant genes
- Populations of non-target organisms (animals, insects, companion crops) can be modified through their interactions with GMO-maize
- Novel pests and diseases
- Further biodiversity loss
- Modified maize and wild relative varieties can out-compete other varieties and induce a significant loss in genetic diversity
- New maize diseases can emerge
- Long-term accumulation of trangenes may eventually disrupt the maize genome
- Other unexpected effects

3.3 Effects of transgenes in a non-industrial farming environment

General Problem: GMO technologies are the most recent chapter of the "farm as a factory" strategy. Ecologically based production problems—induced by land-use intensification, high external inputs, and oversimplification of the agroecosystem—are temporarily solved with a "one problem/one solution" approach. Patentable "magic bullet" inputs may be more effective in the short term, but some may be ecologically less robust than the more social "many little hammers" approach to problem solving in agroecosystem management.

4 Research needs for risk assessment of ecological impacts on maize agroecosystems in Mexico

4.1 Maize agroecosystems are diverse, highly variable and complex—making impact assessment very difficult (opportunities and constraints)

4.2 Requirements for ecological risk assessment of particular transgenic traits

4.3 Risk assessment by comparing different problem-solving strategies in maize agroecosystem management: a transgene approach versus conventional breeding for high-input maize production versus breeding for alternative (organic, ecological, and/or low input) maize production

5 Extensions to other crops and regions

5.1 Extension to other crops in Mexico (cotton, coffee, squash, bananas, wheat, potato, agave, beans, sorghum, tomato, others?)

5.2 Extension to other crops in regions of their origins

Chapter 6 Assessment of Social and Cultural Effects Associated with Transgenic Maize Production

Stephen Brush and Michelle Chauvet

1 Background

1.1 Social and cultural impacts of new technology in agriculture

1.1.1 How to assess impact and difficulty in assigning cause and consequences

- multiple causal factors or social problems
- constant and necessary change in social/economic systems (moving target)

1.1.2 Technology bias (e.g., large versus small farms)

1.1.3 Loss of cultural identity (e.g., absorption into large economic/industrial systems)

1.2 Social groups and social structure of Mexican maize agriculture

1.2.1 Structuring factors: farm size, ethnicity, region, land tenure

1.2.2 Patterns of change

- integration into national market and economic system
- persistence of poverty
- migration and decline in rural sector

1.2.3 State involvement in agricultural development and rural livelihoods

- pressures for technological improvement
- technical assistance (e.g., Plan Puebla, SAM)
- state subsidies and market control

1.3 History of maize management and diversity

1.3.1 Cultural aspects of maize and maize diversity

- selection practices for multiple traits
- seed exchange and change

1.3.2 Maize livelihood (versus maize commodity production)

1.3.3 Use of new technology

- limited adoption of commercial hybrids
- maintenance and criollozation of local types

1.3.4 Social and economic impact of maize technology development in Mexico

1.3.5 Impact of demise of subsidies, technical assistance, and market control (imports)

1.3.6 Relation of transgenic maize to other technological change

2 Potential effects of transgenic maize on farmer choice and rights

2.1 Effects of previous maize improvement on farmer choice (e.g., on practices of seed exchange, experimentation, and partial adoption of new technology)

2.2 Potential effects of transgenic maize—how is it different?

2.3 Farmers' rights (i.e., right to replant, exchange seed)

2.3.1 International Treaty on Plant Genetic Resources for Food and Agriculture

2.3.2 Mexican IPR relating to plant varieties and plant patents

2.4 Potential IPR issues

2.4.1 Distortion of agricultural research agendas (e.g., toward IPR products)

2.4.2 Closure of open seed exchange

3 Potential effects of transgenic maize on productivity, yield, and income

3.1 Multiple determinants of productivity, yield, and income

3.2 Yield effects

3.2.1 Possible differentiation in yield benefits according to environment

3.3 Farm income effects

3.3.1 Possible differentiation of income effects

3.3.2 Difficulty in addressing poverty through technology improvement (e.g., limited income benefits of open pollinated, improved varieties

3.3.3 Potential negative effects: loss of niche markets, export markets, organic producers

4 Effect on cultural practices, identity, and customs

4.1 Maize in Mexican identity (livelihood versus commodity)

4.2 Fluid nature of cultural identity (communication, migration, education) and absorption of new elements

4.2.1 Cultural notion of "criollo" – is transgenic maize different?

4.2.2 Women's participation in technological decisions

4.3 Potential effects because of loss of variability and local autonomy in production

Chapter 7 Assessment of Human and Animal Health Effects

Héctor Bourges and Samuel Lehrer

Questions to be answered:

1 What are the characteristics and levels of nutrition for the Mexican population?
2 What is the importance of maize in Mexican agriculture?
3 What is the role of maize in Mexico for human consumption and animal feed
4 What is the need for transgenic maize varieties or maize varieties with a modified composition?
5 Which transgenic types and traits are currently available in the market or under experimental testing?
6 What are the possible unexpected effects on human and animal health from genetic modifications that have not been resolved?

1 Introduction to the topic: Relation between TG maize and Mexican patterns of nutrition

1.1 Nutrition. Its bio-psycho-social nature

1.2 Diet as the fundamental unit in human nutrition

1.3 Maize in the nutrition of Mexicans

1.3.1 Its historical and current role
1.3.2 Brief historical notes
1.3.3 The meaning of maize for Mexicans, especially for Indians
1.3.4 Tradition, culture
1.3.5 Notes on Indian communities. languages, ethnicity, number of communities

2 Nutrition of the Mexican population

2.1 Protein, energy, malnutrition

2.2 Anemia

2.3 Obesity and chronic disease

2.4 Nature of nutritional problems

2.5 Importance of food production and availability, fortification, … etc.

3 Maize in Mexican agriculture—native varieties and consumption patterns (map of main varieties consumed)

4 Role of maize in Mexico for human consumption and animal feed

4.1 Geographical and socioeconomic distribution

4.2 Culinary aspects: nixtamal and the multiplicity of dishes

4.3 Composition

4.4 Nutrients: protein, energy, fiber, calcium, Niacin, iron

4.5 Ways of consumption: tortilla, flour, many others…

4.6 Direct consumption: exposure historically considered as safe

4.7 Animal feed as part of the integral use of maize: silage, etc.

5 Need for transgenic maize varieties or maize varieties with modified composition

6 Transgenic maize: types and traits

6.1 First generation: approved, well known and well monitored: safe

6.2 Second generation: improved nutritional traits

6.3 Third generation: molecular "pharming" and industrial maize, production of new proteins, lubricant oils, vaccines; needs and dangers

Other commentaries to be incorporated into the text:
Vaccination in Mexico is alright. People's rights for accepting it. Maize is OK the way it is, there are millennia of experience behind it. Therefore, there is no need to change maize. It would be useless, unless real production problems in Mexico could be solved by GM technology. Therefore, we have plenty of time to do it.

7 Unresolved issues

7.1 Unexpected effects due to gene modification: fusion proteins, alteration of metabolic routes, switching-on of genes that were previously non-functional?

7.2 Is there any allergenic potential of maize that has suffered introgression?

7.3 No two-dimensional map available of proteins for Mexican native varieties (proteomics)

7.4 Need for independent studies in humans, long term

Chapter 8 Framework by which Potential Benefits and Risks Can Be Judged

Mauricio Bellon and George Tzotzos

Questions

1 What are the philosophical bases for judging the potential benefits and risks of the introduction of transgenic maize in Mexico?

2 Do the available methodologies for risk assessment and management provide a basis for evaluating human health and environmental risks arising from farm-scale and commercial-scale releases of transgenic maize under the conditions obtaining in Mexico?

3 Are the assumptions that underpin these methodologies valid under the agricultural and social circumstances in Mexico?

4 Do the peculiarities of Mexico as a center of maize diversity with a dual agricultural sector require that modifications should be made to the available methodologies for risk assessment and management? If so, what modifications are required and why? If not, why not?

5 How well do regulators and the public understand GMO-related risks?

6 How should private and public benefits and risks associated with the introduction of transgenic maize in Mexico be weighted?

Outline

1 Risk and democracy

2 The risk assessment approach: Overview of distinct methodologies for risk assessment and approaches/models for risk management

3 The assumptions behind methodologies for risk assessment and approaches/models for risk management

4 Uncertainty and irreversibility in decision-making

5 Dealing with risks in pluralistic societies

6 The peculiarities of Mexico as a center of maize diversity with a dual agricultural sector and their relationship with methodologies for risk assessment and risk management

7 Factors influencing acceptability of risk by governments and the public: the private and public benefits and risks associated with the introduction of transgenic maize in Mexico

8 Drawing a baseline of comparison between risks of transgenic and non-transgenic maize in a dual agricultural sector

9 Institutional approaches (e.g., regulatory agencies) for risk assessment and management and decision making criteria

Chapter 9 Understanding Complex Biology and Community Values: Communication and Participation

Jorge Larson and Michelle Chauvet

Questions:

1 How have farmers, communities and their organizations experienced this process?

2 What are the adequate means to inform them about transgenic, hybrid and land race corn?

3 What mechanism can be used to consult with them about the problem and management options?

4 How can we value with social legitimacy the potential risks and benefits?

5 What mechanisms of access to information and knowledge can be developed?

6 Analysis and evaluation of positive and negative communication and participation experiences on agricultural diversity conservation and the risks of biotechnology in peasant and indigenous scenarios (include a literature review and perhaps reports on field work in Mexico and in the Potato Park in Cuzco, Peru, January 2003).

7 General documentation to analyze and evaluate the information and knowledge available to communities about maize land races and transgenics before and after we knew about the introgression (support with interviews, compilation and analyses of documents and press distributed or presented to farmers, communities or organizations).

8 Documented communication experience about the scope of the CEC report to the *Comité de Recursos Naturales de la Sierra* (November 2003).

9 Collectively constructed proposals and recommendations about communication-participation processes regarding the impacts of GM maize and management alternatives. General strategic suggestions about communication-participation related to the risks of biotechnology and *in situ* conservation in centers of agricultural diversity.

Chapter 10 Identification and Analysis of Management Tools and Options to Mitigate or Avoid the Potential Risks and to Enhance or Realize the Potential Benefits

Reynaldo Ariel Alvarez-Morales and John Komen

Transgenic Maize in its Center of Origin: The Mexican Case

The preceding chapters of the CEC volume will have addressed a wide range of aspects of the current debate on transgenic maize in Mexico. Chapter 10 will attempt to suggest a way forward, and focus on recommending a set of tools and policy options to manage potential risks and to enhance potential benefits. Main elements of the chapter will be:

Specific questions to be addressed by the authors—with particular reference to the situation in Mexico where possible—include the following:

1 Rationale for applying GM technology in developing countries, and associated issues

- Current applications and traits—overview
- Applications for industrial-scale growers (hybrids: biological means to control transgene dispersal)
- Applications for small-scale growers (open pollinated: loss of transgene control and subsequent dispersal)

2 Enhancing the (potential) benefits

- Evidence of farm-level impact to date (e.g., Bt cotton in Mexico)
- Scientific advances, future traits that may enhance benefits (e.g., Al tolerance)
- Policies and regulatory dimensions, including biosafety

3 Managing (potential) risks

- Evidence to date on environmental impacts
  - Geneflow in centers of origin or diversity, possible consequences for land races and wild relatives
  - Agrobiodiversity: Land race disappearance or preservation through biotechnology
  - Potential impact of transgenic maize on biodiversity
- Biosafety policies and procedures: Key decision points and policy options
- Scientific advances can mitigate GMO risks

4 Monitoring the release of GM crops

- Who should monitor?
- What should be monitored?
- Where should it be carried out?
- For how long?
- Who should pay?

5 Conclusions and recommendations