For W. Schanbacher, ed., *The Global Food System: Issues and Solutions* (Praeger 2014)

The GMO threat to food sovereignty: Science, resistance and transformation

– Brian Tokar

The expansive use of genetically modified organisms (GMOs) in agriculture is one of the most potent symbols of the worldwide threat to food justice and food sovereignty. Today over 365 million acres worldwide is believed to be planted in GMO varieties of soya, maize, cotton and other crops.[1] Even though the vast majority of GMO crops are still raised in a small handful of countries, mainly in the Western hemisphere, they include agroexport giants such as the US, Argentina and Brazil. Much of the world, however, is continuing to resist this uniquely controversial and invasive form of genetic manipulation of our food.

A significant milestone in the global response to GMOs was achieved in July of 2013 when, after more than seventeen years of popular campaigns, lawsuits, diplomatic maneuvers and political battles, Monsanto announced it would cease its effort to gain approval to grow any more GMO crop varieties in Europe.[2] Ten years prior, the G.W. Bush administration in the US filed a lawsuit with the World Trade Organization seeking to pry open Europe's approval processes. After three years of deliberations, the WTO ruled that Europe's *de facto* moratorium on new approvals had to be replaced by more specific case-by-case approval processes, but the transnational body upheld European countries' right to protect food safety and the integrity of local agricultures. In that ruling, countries retained the ability to consider all possible hazards of GMOs in their risk assessments, even those that are perceived to be "highly unlikely to occur."[3] By 2013, even Monsanto apparently conceded that the unified opposition of European consumers, farmers and many independent scientists was not likely to be overturned.

Opposition to GMOs also arose throughout the global South as soon as the first engineered crop varieties were introduced in the late 1990s. Militant farmers' campaigns in India with names such as "Cremate Monsanto" and "Monsanto Quit India" made international headlines.[4] Farmers in Mali and South Africa organized against the introduction of GMO maize varieties, and Zambia took the unprecedented step in 2002 of refusing food aid shipments containing GMO corn from the US.[5] In Brazil, where food crops, grazing lands and vast tracts of former Amazon rainforest have been overtaken by plantations of GMO soybeans grown mainly for export, farm activists and women's groups associated with the global La Vía Campesina alliance have occupied seed facilities and research plots managed by Monsanto and Syngenta on numerous occasions. A prominent leader of Brazil's renowned Landless Workers' Movement (MST) was assassinated by Syngenta's private security forces during one of these actions.[6]

A 2012 joint report on Monsanto by Vía Campesina and Friends of the Earth International concluded, in part:

> As a result of Monsanto's presence, local seeds are becoming illegal, biodiversity is disappearing, land is being contaminated, and farmers and agricultural workers are being poisoned, criminalised and displaced from their land. Local food producers aiming to feed communities have to compete with huge corporations whose sole objective is to make profits.
>
> … With the current economic and environmental crises, global resistance against transnational corporations has become an urgent necessity. A fair society organised to address people's needs and guarantee their rights cannot be built in co-existence with corporations that grab power and finite resources.[7]

Many years earlier, Vandana Shiva wrote,

> [C]orporations that promote genetic engineering steal nature's harvest of diverse species, either by deliberately destroying biodiversity or by unintended biological pollution of species and ecosystems. They steal the global harvest of healthy and nutritious food. Finally, they steal knowledge from citizens by stifling independent science and denying consumers the right to know what is in their food.[8]

How did a novel agricultural technology, advanced by just a handful of corporations, become such a powerful driver of the increasing global corporate control over the world's food supply? How did Monsanto and others achieve unprecedented dominance over the world's seed supplies, and what alternatives have emerged to help enhance people's ability to adequately feed themselves?

The new seed cartel

Since the mid-1990s, a handful of corporations specializing in the production of pesticides and other agrochemicals have aggressively promoted the genetic engineering of crops and seeds, insisting that this technology is the key to improving world agriculture. Meanwhile, they have furthered the steady expansion of GMO technology by steadily increasing their control over the world's seed supply, mainly through outright purchases of major seed companies. Monsanto, one of the world's top chemical producers throughout the 20th century, is by far the most aggressive promoter of genetic engineering, and by 2005 held patents to varieties grown on 88 percent of all GMO crop acreage.[9]

That same year, Monsanto became the world's largest seed company with its takeover of Seminis Seeds, a Mexican company that had become the premier supplier of vegetable seeds in the Western Hemisphere. A generation or two ago, seed production was a highly dispersed activity, one that still operated largely outside the commercial sphere in much of the world. Today, the informal sector in the seed trade still thrives in many areas, but is under increasing economic and legal pressure from the new global seed cartel. Ten companies now control more than three-quarters of a worldwide seed market valued $34.5 billion annually.[10] Five of those companies, Monsanto, Syngenta, Bayer, Dow and DuPont, are also (along with BASF) the world's dominant producers of agricultural chemicals, and are responsible for nearly all of the genetically engineered seed varieties marketed around the world today. Monsanto itself became increasingly specialized in seeds and agrochemicals, spinning off its various industrial chemical and pharmaceutical divisions and spending much of the proceeds – at least $12 billion – buying up the world's leading seed companies, from DeKalb and Asgrow in the US to Seminis in Mexico and India's flagship Mahyco, formerly the Maharashtra Hybrid Seed Company.[11]

All of these companies are, in their present form, the result of an extensive series of corporate mergers and divestments that shaped the emerging biotech era in the late 1990s and early 2000s.[12] Bayer, best known for aspirin and other common pharmaceuticals, is also the world's largest producer of insecticides. Following a corn contamination scandal in 2000-'01 that cost the food industry $1 billion—and forced the recall of hundreds of name brand corn products due to contamination with a GE variety never approved for human consumption (see below)—Bayer bought the former "CropScience" division of the pharmaceutical giant Aventis. Syngenta is a perhaps a uniquely synthetic company, formed from successive waves of mergers, spinoffs and recombinations of chemical companies from Switzerland, Britain and Sweden; they are the number two manufacturer of pesticides worldwide, after Bayer, and the largest producer of herbicides.

Monsanto remains the second largest producer of chemical weed-killers, and thus it is no coincidence that tolerance to herbicide treatments is by far the most dominant genetically engineered trait in commercial agriculture today; up to 90 percent of all GMO crops include some form of engineered tolerance to herbicides, especially Monsanto's various "Roundup" formulations. Engineered herbicide tolerance has made it easier for some growers to plant vast acreages of corn and soybeans on fields that are frequently doused with broad-spectrum herbicides like Roundup that destroy most other plants. This has reduced the need for mechanical cultivation and helped popularize the spread of a highly chemical-dependent form of nominally "no-till" agriculture. This technology has led to such a rapid increase in herbicide use that "super weeds" with an evolved resistance to Monsanto's Roundup and other broad-spectrum herbicides have now come to dominate fields in many parts of the US.[13] The other common category of GMO crops produce one or more pesticidal proteins, derived from *Bt* (*Bacillus thuringiensis*) bacteria; these insecticidal varieties of corn, cotton and other crops are regulated as insecticides by the US EPA. Current GMO crop varieties often combine both types of traits in multiple forms, a technology known as "gene stacking."

Farmers in the corn and soy-growing regions of the US report that Monsanto and other companies have leveraged their control over the seed market to make it increasingly difficult to obtain seeds with the latest agronomic improvements – traits introduced entirely through conventional plant breeding – unless farmers are willing to purchase patented GMO seeds. The latest products of US breeding labs – also increasingly under corporate control – are often only available with various proprietary GMO herbicide tolerance and *Bt* insecticidal traits attached.[14] The remaining non-GMO seed supplies are often not reliably so: a 2004 study commissioned by the Union of Concerned Scientists detected transgenic DNA in 50-80 percent of the nominally non-GMO corn seed that was tested, 50-80 percent of the soybeans and 80-100 percent of the canola seed.[15] Globally, companies have intervened in international trade negotiations to press for increased legal restrictions on farmers' ability to freely exchange seeds. For example, recent US bilateral free trade agreements include provisions that force the adoption of "plant protection" rules that have long been advocated by GMO seed producers.[16]

Throughout North America, Monsanto has also pursued legal cases against hundreds of farmers who have been accused of illegally saving seeds and replanting patented GMO varieties without the company's consent. The Washington-based Center for Food Safety has been monitoring these lawsuits closely for over a decade, and, as of late 2012, documented 142 lawsuits against 410 farmers in 27 US states.[17] The company has reportedly investigated as many as 4500 farmers for so-called "seed piracy." Some of those growers openly defied the company's patents, asserting their right to the time-honored practice of farmers saving and replanting seeds, while others were simply victims of inadvertent contamination of their seed stocks. In the most celebrated case of all, a Saskatchewan farmer named Percy Schmeiser replanted some canola (rape) seed that had apparently cross-pollinated with a neighbor's Monsanto Roundup-tolerant variety in an attempt to salvage the results of some thirty years of his own breeding research and crop development. The Canadian Supreme Court ultimately ruled that Monsanto had the right to sue Schmeiser to protect the company's patent rights, but overturned all the monetary damages that had been imposed by a lower court. The Supreme Court affirmed in its decision that, as a non-user of Roundup-family herbicides, Schmeiser had obtained no tangible benefit from Monsanto's GMO traits.[18]

So it is by virtue of their raw monopoly power, rather than any demonstrable advantages of GMOs, that Monsanto and other companies have come to dominate supplies of several important staple crops. It is clear that GMO crops have not been responsible for any reliable increase in yields over equivalent non-GM crops, and have generally increased farmers' dependence on agricultural chemicals.[19] Twenty years of claims that genetic engineering will "feed the world" by making crops more resilient and healthier have time and again proven false. Instead, they have created new oligopolies in key agricultural inputs, including seeds, and helped advance the trend toward increasing mechanization and concentration of ownership of farm land.

Monopolizing Science

While Monsanto and other GMO developers often caricature their opponents as "anti-science," the biotech industry itself has significantly undermined the integrity of genetic science and worked to demonize independent scientists who raise criticisms of their technology. Some essential realities that the industry has worked hard to suppress include:

- The artificial insertion of new genes into the embryonic cells of our basic food crops is inherently disruptive of those cells' own internal processes of genetic regulation.

- The genetic material (DNA) that is forcibly introduced through genetic engineering is not merely extracted from other living cells, but is generally a wholly artificial construct, including added regulatory and marker sequences from viruses and other organisms. These added components are necessary to overcome living cells' evolved resistance to unfavorable genetic alterations, and to help identify the minuscule proportion of cells in most experiments that actually express the inserted transgenic traits.

- Partly due to these added components, genetic engineering is associated with very high levels of genome scrambling, disruption, and unusually high mutation rates.

- Most attempts to introduce agronomically significant traits through genetic engineering have not been successful, and conventional plant breeding is usually far better able to confer the advantages in crop yield, tolerance to environmental stresses, and other qualities that genetic engineers continue to tell us are just over the horizon.

- Monsanto, DuPont, and other companies have leveraged their patents over key GMO traits to limit independent scientists' access to important research materials.

- When studies appear that confirm significant health consequences from exposure to GMO crops, companies are often actively involved in efforts to demean and discredit the scientists involved, both within the scientific community and on the internet.

Comprehensive studies of the health and environmental effects of GM crops remain relatively sparse. This is largely a consequence of Monsanto's unprecedented influence within some scientific circles and their often covert involvement in aggressive smear campaigns against researchers who may publish objectionable findings. Researchers such as Arpad Pusztai in Scotland, Gilles-Eric Séralini in France, Irina Ermakova in Russia and many others have published detailed studies showing that animals fed GMO grains suffer higher rates of organ damage, loss of fertility, suppressed immunity, and other negative health consequences. Instead of these studies sparking additional research in these areas, as would normally occur in a climate of open scientific inquiry, each fell victim to organized campaigns to discredit the researchers and their findings in both the scientific and popular press.[20] Combined with biotech companies' proprietary ownership of various GMO varieties, this has led to a situation where the effects of GMOs remain significantly under-researched. For example, entomologists engaged in studies of crop pests have petitioned the EPA citing numerous ways in which their research is undermined by corporate patent rules.[21]

Cellular and molecular-level research, on the other hand, substantially affirms that technologies of gene splicing are inherently disruptive to cellular metabolism and the regulation of gene expression. In a detailed analysis of over 200 published research studies, researchers in the UK documented significant increases in genetic instability, higher mutation rates, large scale deletions and translocations of DNA, and other disturbing effects at the sites of artificial gene insertion.[22] This study also helped reveal the extent to which research on the cellular and molecular consequences of genetic engineering tends to lag many years behind corporate-funded research focused almost entirely on the development and commercialization of new products.

Research on the environmental consequences of GMOs has also languished since the technology's early years. In 1999, scientists at Cornell University made world headlines with their announcement that pollen from a common variety of insecticidal *Bt* corn was lethal to monarch butterflies in their larval (caterpillar) stage.[23] While later studies claimed to refute this finding, it was indeed confirmed that some *Bt* toxin proteins that had been used in commercial GMO crop varieties did kill monarch caterpillars. Studies suggesting harm to agriculturally beneficial insects such as ladybugs and lacewings were for the most part not followed up by subsequent researchers.[24] Meanwhile in 2011, a new study suggested that the main threat to monarch butterflies may indeed be an indirect consequence of the spread of GMOs. Monarchs' main feeding source in their larval stage is milkweed, which grows most abundantly in and around Midwestern cornfields. With the rapid spread of herbicide tolerant corn varieties, weeds such as milkweed are eradicated due to the increased use of broad-spectrum herbicides such as Roundup throughout the main corn-growing areas of the country, hence depriving the caterpillars of their most important food source.[25]

Genetic Drift

The destabilizing environmental effects of genetic engineering are not limited to the laboratory nor to just a few charismatic organisms. One early study suggested that genetically engineered plant varieties may be inherently more likely to outcross than their non-GMO relatives, and the consequences of genetic contamination were demonstrated countless times in the first 15 years of the GMO era.[26] Since 2005, Greenpeace, in collaboration with GeneWatch in the UK has maintained an online database of GMO contamination incidents, the GM Contamination Register.[27] An initial summary report in 2006 listed 142 publicly documented incidents in 43 countries since the introduction of commercial GMO crops in 1996. These included instances of contamination of food, seed, animal feeds, and wild relatives of crops, as well as illegal releases of unapproved GM varieties and documented negative agricultural side effects.[28] As of September 2013, the database contained a total of 384 entries.

Some of the better-known incidents that have alerted the world to the widespread contamination potential from GMO crops include:

- In 2001, researchers in the state of Oaxaca, Mexico documented the presence of DNA from GMO corn varieties in several indigenous corn crops.[29] A largely methodological dispute over the extent of contamination within the corn genome generated so much controversy that the journal *Nature* took the unusual step of withdrawing the original research paper and Ignacio Chapela, the principal investigator, faced continued media attacks on his scientific reputation. Meanwhile, the fact of widespread corn contamination in Mexico has since been confirmed by numerous independent and governmental studies.[30]

- In 2000, US domestic corn supplies were widely contaminated with a GMO trait, known as Starlink (a *Bt* insecticidal protein known as Cry9C), which EPA regulators had previously declined to approve for human consumption. Some 300 consumer products were recalled, costing the food industry approximately $1 billion, including $110 million to settle claims from corn growers due to persistent marketing difficulties. Over 400 million bushels of corn were found contaminated with the Starlink trait, even though less than 40 million bushels of Starlink corn were harvested the previous year; 8.6% of all US corn tested in 2000 was found to contain the Starlink trait.[31] Contaminated grain continued to be found in 1 percent of samples taken three years after the corn was withdrawn from the market, and a recent study published in the journal *Applied Biochemistry and Biotechnology* reported detection of numerous banned and discontinued GMO varieties, including Starlink, in samples of corn and soy products purchased in Saudi Arabia.[32]

- Researchers in the Canadian province of Alberta identified plots of oilseed rape (canola) that were simultaneously resistant to three common herbicide classes: glyphosate (Monsanto's "Roundup"), glufosinate (Bayer's, originally Aventis', "Liberty") and imidazolinones (Cyanamid's imazethapyr formulations, "Pursuit" and "Odyssey"). A nearby grower had been cultivating GMO varieties demonstrating the first two resistances, as well as a non-GMO rape tolerant to imidazolinones.[33] A follow-up study detected resistant plants as far as 500 meters from the original plantings, and confirmed through detailed DNA analysis that the multi-resistant plants "were hybrids resulting from pollen transfer rather than inadvertent seed movement between fields."[34]

- In 2006, the US Secretary of Agriculture announced that the US long grain rice crop had been contaminated with an experimental glufosinate-tolerant variety (marketed as "LibertyLink") that was developed and field tested by Bayer CropScience. Even though no variety of GMO rice has yet been deregulated by the US Department of Agriculture for commercial production, and field trials were reportedly less than one acre in size, glufosinate tolerance and two other GMO traits were subsequently identified in rice exported to Europe, the Middle East, Asia and Africa.[35] The US rice grower Riceland reported that the contamination was "geographically dispersed and random" throughout the long grain rice growing areas of the southeastern US, and the US Government Accountability Office later reported that the incident cost as much as $1.29 billion in lost exports, food recalls and other expenses.[36] In 2011, Bayer agreed to pay 11,000 farmers in five US states a total of $750 million to settle numerous pending lawsuits from this incident.[37]

- In at least two documented incidents, crops in the US Midwest were contaminated with residues from prior year experimental plantings of crops genetically engineered to produce pharmaceutical ingredients. In Nebraska, 500,000 bushels of soybeans had to be destroyed and 155 acres of corn burned when residues were detected from an experimental corn variety engineered to produce a pig vaccine. In Iowa, commercial corn crops were contaminated by residues of a previously grown GM variety that produced an experimental drug for cystic fibrosis.[38] These two incidents raised widespread concerns among US food producers about potential pharmaceutical contamination of food, bankrupted the company (ProdiGene) responsible for these two incidents, and led others in the US biotech industry to ultimately abandon the strategy of producing pharmaceuticals in GM food crops.[39]

- Plantings in Hawaii of a GMO papaya variety resistant to the ringspot virus led to widespread contamination of the islands' papaya crop. A sampling of 20,000 seeds from organic and wild papaya plantings found that 50% of the sampling sites were contaminated with the engineered trait.[40] Along with marketing problems that drove the Hawaiian papaya crop to a 25-year low, and contamination of many traditional papaya varieties, the engineered papayas were found to be unusually susceptible to other viral and fungal diseases.[41] Large scale GMO contamination of papayas was also documented in Thailand, most likely from unapproved research trials, and samples of unauthorized GMO Hawaiian papaya appeared in several European countries in 2013.[42]

- In 2004, researchers from the US Environmental Protection Agency investigated native grass contamination in the state of Oregon from a test plot of creeping bentgrass genetically engineered for Roundup tolerance. They found numerous grasses within 2 kilometers of the experimental plot, and two samples up to 13 miles away, that survived spraying with Roundup and also contained major components of the inserted DNA that imparts this trait.[43] Two years later, researchers determined that the transgene had established itself in resident grass populations, as well as in a non-GMO bentgrass that had been planted nearby to aid in monitoring potential gene flow.[44] They determined that the contamination had resulted both from the spread of pollen and from dispersed GMO seeds, a surprise given the minimal selective advantage of herbicide tolerance in areas that are not treated with herbicide.

- In 2013, several wheat plants resistant to applications of Roundup herbicide were found in a farmer's field in eastern Oregon. Monsanto had received approval from the US Department of Agriculture to test herbicide tolerant wheat varieties

> in 1998, but the tests were reportedly ended in 2005, when the company chose not to market GMO wheat following widespread opposition from farmers and consumer groups worldwide; Monsanto had reportedly resumed testing GMO wheat varieties in Hawaii in 2012. Japan, Taiwan and South Korea subsequently suspended imports of wheat from the Northwestern US for more than two months.[45]

Several researchers have reviewed the inherently disruptive character of genetic modifications for gene expression, ecological fitness and production of potentially dangerous new gene products. In one review essay, Allison Snow of Ohio State University wrote:

> Although crops and weeds have exchanged genes for centuries, genetic engineering raises additional concerns because it not only enables introduction into ecosystems of genes that confer novel fitness-related traits, but also allows novel genes to be introduced into many diverse types of crops, each with its own specific potential to outcross.[46]

Feeding the World?

Facing continuing opposition to GMOs on so many scientific, economic and political grounds, Monsanto and other companies continue to assert the claim that their technology is necessary to feed the world. Several recent studies affirm that locally-scaled, peasant agricultures are far better able to feed hungry people than all the innovations of global agribusiness.[47] Still, the promise of GMOs "feeding the world" remains at the center of industry efforts to bolster its reputation. The industry has supported numerous high-profile research efforts aimed at demonstrating its purported benefits for people in the global South, but each in turn has raised more questions than answers.

Many efforts to introduce GMOs to the global South have been generously supported by global institutions such as the World Bank. In the first few years of the GMO era, the Bank provided some $50 million in direct aid for biotechnology research, with over 80 percent of research funding committed to six countries: India, Kenya, Brazil, Indonesia, Peru, and Ethiopia. India alone received a full 40 percent of the total, with $20 million in World Bank funds supporting the development of an insecticidal *Bt* rice, along with genetically engineered varieties of cotton, pigeon peas, chickpeas, and various horticultural crops.[48] In recent years, the Bill and Melinda Gates Foundation has invested heavily in agricultural technologies for the developing world, investing $1.3 billion in the late 2000s alone, and with a consistent focus on biotechnology applications.[49]

In one high profile project, announced in 2003, genes from amaranth were spliced into the DNA of potatoes to increase their protein content for use in India. While the protein content of the potatoes reportedly increased by nearly half, it was only a small fraction of the amount found in whole amaranth, or even in wheat and rice. GMO opponents in India pointed out that the peas, lentils, and other legumes that are an important part of traditional Indian diets — but have been marginalized in cash crop-oriented agricultural development projects — provide even more protein.[50] Many in India concluded that biotechnologists were promising a high-tech "cure" to hunger, while ignoring far more realistic and readily available solutions, a recurring theme in many global South applications of genetic engineering.

In Kenya, the World Bank joined forces with the US Agency for International Development (USAID), Monsanto and other private donors. There, the aim was to offer engineered varieties of sweet potatoes, a staple crop in rural areas that rarely attracts the interest of corporate researchers. After 11 years of research, which generated much international publicity for the Monsanto- and USAID-sponsored Kenyan researcher Florence Wambugu, only one local sweet potato variety had successfully been genetically engineered, imparting resistance to a virus that farmers routinely fend off by far less invasive means.[51] Under field conditions, the potato failed to demonstrate any significant virus resistance.[52]

Perhaps the most controversial GMO application in India has been the marketing of *Bt* insectidical cotton varieties to small-scale growers in many parts of the country. While *Bt* cotton has become dominant in regions of India where larger-scale cultivation is common, Monsanto has aggressively marketed its "Bollgard" brand to India's innumerable smallholders as well, promising crops that will resist infestations of the dreaded bollworm. From the first approved cultivation of *Bt* cotton in 2002, however, many farmers faced almost total crop failures, as their crops were found to be even more vulnerable to various other cotton pests, including budworms, mealybugs, and several fungi and viruses.[53] Some critics blame the rising use of GMO crops and the resulting unprecedented increase in seed prices and pesticide dependence for driving perhaps hundreds of thousands of Indian farmers to suicide in recent years, though others suggest that farmer suicides were a chronic tragedy in Indian communities even before the GMO era.[54]

Of all the various GMO crops developed for global South applications, perhaps the most worldwide attention has focused on so-called "golden rice," a rice genetically engineered with daffodil and bacterial DNA to produce elevated quantities of beta-carotene, a biochemical precursor of vitamin A. Researchers in Switzerland, Germany, and India reportedly spent $100 million developing this experimental rice variety, which in its first iteration, would have required a person to eat twelve times their normal dietary intake of rice to receive the promised benefit.[55] The renowned food writer Michael Pollan thus described it as "the world's first purely rhetorical technology."[56] Even if current varieties produce significantly higher provitamin doses, as is claimed, critics continue to raise numerous questions about its metabolism, potential side-effects, and whether the funds may have been better spent purchasing inexpensive vitamin A supplements and helping poor communities sustain their traditional dietary vitamin A sources, including leafy green vegetables, carrots, squashes, sweet potatoes, melons, mangos, eggs, and butter. Meanwhile, Brazil's public agricultural research agency, Embrapa, has announced varieties of eight staple crops with dramatically enhanced levels of provitamin A and other micronutrients, developed entirely through conventional plant breeding and already being introduced into local school lunch programs.[57]

Indeed a growing body of evidence suggests that scientific applications of traditional, time-tested crop improvement methods may have far more potential to help address the world's food needs than any of the biotechnology industry's proposed solutions. A study by Jules Pretty at the University of Essex (UK) surveyed more than 200 sustainable agriculture projects in 52 countries and showed how a variety of relatively familiar techniques have the potential to dramatically improve crop yields in the global South. Low-tech methods such as trap crops for insects, careful applications of compost, use of natural predators for common insect pests, and a wealth of traditional intercropping methods have demonstrable advantages, especially when applied in a systematic and consistent manner.[58] One Chinese study showed that simply interplanting two different rice varieties with distinctly different growing characteristics had the effect of doubling yields.[59] Farmers in India have helped advance a system of "root intensification," through which yields of rice, wheat and many vegetables are multiplied several fold by adjusting methods of planting and cultivation, with the added benefit of requiring less water. The system combines some indigenous methods with others that were developed in Africa in the 1960s, but often ignored by development officials with close ties to international foundations and research institutes.[60]

Miguel Altieri of the University of California at Berkeley, a central figure in the development of agroecology writes:

> The persistence of millions of agricultural hectares under ancient, traditional management in the form of raised fields, terraces, polycultures (with a number of crops growing in the same field), agroforestry systems, etc., document a successful indigenous agricultural strategy and constitutes a tribute to the "creativity" of traditional farmers. These microcosms of traditional agriculture offer promising models for other areas because they promote biodiversity, thrive without agrochemicals, and sustain year-round yields. The new models of agriculture that humanity will need include forms of farming that are more ecological, biodiverse, local, sustainable, and socially just. They will be rooted in the ecological rationale of traditional small-scale agriculture, representing long- established examples of successful community-based local agriculture. Such systems have fed much of the world for centuries and continue to feed people across the planet.[61]

The systematic advantages of traditional crop varieties and growing methods over those of agribusiness and biotechnology corporations may be even greater in the area of crop adaptation to disruptive changes in the earth's climate. For two decades, GMO proponents have suggested that biotech interventions would prove necessary for the world's food supply to withstand the stress of rising temperatures and erratic precipitation patterns associated with global climate change. In 2008 the Ottawa-based ETC Group identified over 500 patent filings for genes associated with climate-adaptive traits; just three years later the number of patents and applications had increased by an additional 50 percent.[62] In 2012, Monsanto released its first drought-tolerant GMO corn, but studies suggest that its ability to withstand modest droughts offered no discernable advantage over products of traditional plant breeding, nor various approaches focused on agroecosystem enhancement without genetic engineering.[63] In 2009, a major study on agriculture and climate by four UN agencies and the World Bank partly anticipated these outcomes, arguing that sustainable agricultural practices rooted in traditional and local agricultural knowledge are the primary strategies for both climate mitigation and reduction of poverty.[64]

Several comprehensive research efforts have confirmed that organic growing methods are generally associated with higher levels of stress tolerance in plants than conventional chemical-intensive methods. A 2005 study reviewing 22 years of organic crop trials at the Rodale Research Institute in Pennsylvania concluded that not only can organic growers achieve comparable yields with far less fossil energy and improved water conservation, but that organic corn yields were consistently higher in drought years than crops from conventionally cultivated fields.[65] A 2007 review compared over 100 studies each of conventional and organic growing methods, and suggested an enhanced organic yield advantage in developing world applications.[66] In 1998, in the aftermath of a hurricane that devastated large areas of Central America, farmers who used cover crops, intercropping and agroforestry methods suffered less damage than their neighbors utilizing agribusiness-approved methods, reporting less topsoil loss and lower economic losses overall.[67] Organic methods also demonstrate specific advantages for climate mitigation, including increasing soils' ability to sequester carbon, reducing nitrogen emissions associated with chemical fertilizers, eliminating energy-intensive pesticide production, composting instead of burning crop residues, and feeding ruminants less grain and more grass, thus helping reduce methane emissions.[68]

Despite overwhelming evidence to the contrary, proponents of genetic engineering continue to assert that GMO research is essential to feeding the world's hungry in an increasingly uncertain and unstable climate. They reiterate the promises they have offered since the dawn of the GMO era, insisting that numerous long-promised advantages will surely be revealed with further study. Meanwhile, the innovations that best serve the needs of both farmers and communities throughout the world continue to emerge mainly from applications of far less invasive methods. In some instances, laboratory techniques developed by biotechnologists are helping facilitate breeding research, offering useful diagnostic tools to better identify desirable traits and monitor the results of breeding experiments. These methods, for the most part, appear far less problematic than manipulations of crop genetics using genetic engineering, and may continue to play a positive role in breeding research in various public and private settings.

Crop genetic engineering, on the other hand, may be a technology whose time has passed. After more than 20 years of research and development, GMOs continue to present far more problems than benefits, and most of the purported advantages have proved limited at best; many simply do not withstand scientific scrutiny. Perhaps it is time to put this inherently problematic and invasive technology aside and instead redouble efforts around the world to advance far more benign and sustainable ways to improve the quality and availability of our food.

Notes

[1] Joseph Zacune, *et al.*, *Combatting Monsanto: Grassroots resistance to the corporate power of agribusiness in the era of the 'green economy' and a changing climate*, La Vía Campesina and Friends of the Earth International, March 2012. The source describes this as 3 percent of agricultural land, but the UN FAO's figure excluding pasture lands from its estimate brings it closer to 10 percent. See also J. Zacune, "Who Benefits from GM Crops? An industry built on myths," Amsterdam: Friends of the Earth International (February 2011).

[2] Anna Meldolesi, "Monsanto waves white flag," *Nature Biotechnology*, September 2013.

[3] WTO Findings document WT/DS291-93/INTERIM, 2006, p. 1031, quoted in B. Tokar, "WTO vs. Europe: Less—and Also More—Than it Seems," at *http://www.zmag.org/content/showarticle.cfm?ItemID=9734*.

[4] Vandana Shiva, "Seed Satyagraha: A movement for farmers' rights and freedoms in a world of intellectual property rights, globalised agriculture and biotechnology," in B. Tokar, ed., *Redesigning Life? The Worldwide Challenge to Genetic Engineering* (London: Zed Books, 2001).

[5] M.M. Lewanika, "GMOs and the Food Crisis in Zambia," in B. Tokar, ed., *Gene Traders: Biotechnology, World Trade and the Globalization of Hunger* (Burlington, VT: Toward Freedom, 2004).

[6] Isabella Kenfield, "Expansion of Biotechnology in Brazil Brings Violence," Center for International Policy Americas Program Special Report, March 2008, at http://americas.irc-online.org/am/5070. For background, see M. E. Martínez-Torres and P. M. Rosset, "La Vía Campesina: Transnationalizing Peasant Struggle and Hope," in R. Stahler-Sholk, *et al*., eds., *Latin American Social Movements in the Twenty-First Century: Resistance, Power and Democracy* (Lanham, MD: Rowman & Littlefield, 2008)

[7] J. Zacune, *et al*., *Combatting Monsanto*, p. 27.

[8] Vandana Shiva, *Stolen Harvest: The Hijacking of the Global Food Supply*," (Cambridge, Massachusetts: South End Press, 2000) p. 95.

[9] ETC Group Communiqué No. 91, *Oligopoly, Inc. 2005: Concentration in Corporate Power*, (Ottawa: ETC Group, November 2005).

[10] ETC Group Communiqué No. 111, *Putting the Cartel before the Horse ... and Farm, Seeds, Soil, Peasants, etc.: Who Will Control Agricultural Inputs, 2013?* (Ottawa: ETC Group, September 2013).

[11] Brian Tokar, "Monsanto: A Profile of Corporate Arrogance," in Edward Goldsmith and Jerry Mander, eds., *The Case Against the Global Economy* (London: Earthscan Publications, 2001).

[12] Hope Shand, "Gene Giants: Understanding the 'Life Industry'," in B. Tokar, ed., *Redesigning Life?*

[13] Charles M Benbrook**, "**Impacts of genetically engineered crops on pesticide use in the U.S. – The first sixteen years," *Environmental Sciences Europe* **24**:24 (2012); Jerry Adler, "The Growing Menace from Superweeds," *Scientific American*, May 2011; Natasha Gilbert, "Case studies: A hard look at GM crops," *Nature* Vol. 497, May 2, 2013; Scott Kilman, "Superweeds Hit Farm Belt, Triggering New Arms Race," *Wall St. Journal*, June 4, 2010.

[14] The same six companies that dominate global agrochemical production account for 76% of private expenditures in seed and agrochemical research and development. See ETC Group Communiqué #110, *Gene Giants Seek "Philanthrogopoly"* (Ottawa: ETC Group March 2013).

[15] Margaret Mellon and Jane Rissler, *Gone to Seed: Transgenic Contaminants in the Traditional Seed Supply* (Washington: Union of Concerned Scientists, 2004).

[16] ETC Group Communiqué No. 111, *Putting the Cartel before the Horse ...*

[17] "Monsanto v. U.S. Farmers 2012 Update," Washington: Center for Food Safety, November 2012.

[18] K. Makin and A. Dunfield, "Monsanto wins key biotech ruling," *Globe and Mail*, May. 21, 2004; "Percy Schmeiser claims moral and personal victory in Supreme Court decision," at http://www.percyschmeiser.com/decisioncomments.htm (accessed May 28, 2004); "Monsanto Canada Inc. v. Schmeiser" decision, May 21, 2004 (2004 SCC 34, File No.: 29437).

[19] Doug Gurian-Sherman, *Failure to Yield: Evaluating the Performance of Genetically Engineered Crops* (Washington: Union of Concerned Scientists, 2009); Benbrook**,** "Impacts of genetically engineered crops on pesticide use in the U.S."

[20] Several such studies, and their political fallout, are summarized in Michael Antoniou, *et al*., "GMO Myths and Truths: An evidence-based examination of the claims made forthe safety and efficacy of genetically modified crops," (London: Earth Open Source, June 2012).

[21] Andrew Pollack "Crop Scientists Say Biotechnology Seed Companies Are Thwarting Research," *New York Times*, February 29, 2009.

[22] Allison Wilson, *et al*., *Genome Scrambling - Myth or Reality? Transformation-Induced Mutations in Transgenic Crop Plants* (Brighton, UK: Econexus, October 2004). See also, Jonathan R. Latham, et al., "The Mutational Consequences of Plant Transformation, *Journal of Biomedicine and Biotechnology*, Vol. 2006, pp. 1-7 (2006).

[23] John Losey, *et al*., "Transgenic pollen harms monarch larvae," *Nature* Vol. 399, 1999, p. 6733.

[24] Early studies on the environmental effects of GMOs are reviewed in Ricarda Steinbrecher, "Ecological Consequences of Genetic Engineering," in B. Tokar, ed., *Redesigning Life?*

[25] Andrew Pollack, "In Midwest, Flutters May Be Far Fewer," *New York Times*, July 12, 2011.

[26] Joy Bergelson, *et al*., "Promiscuity in transgenic plants," *Nature* Vol. 395, September 3, 1998, p. 25.

[27] http://www.gmcontaminationregister.org/

[28] Greenpeace International, *GM Contamination Register Report: Annual review of cases of contamination, illegal planting and negative side effects of genetically modified organisms*, February 2007, at http://www.genewatch.org/uploads/f03c6d66a9b354535738483c1c3d49e4/gm_contamination_report_2006.pdf.

[29] David Quist and Ignacio Chapela, "Transgenic DNA introgressed into traditional maize landraces in Oaxaca, Mexico," *Nature*, Vol. 414, pp. 541-543, November 29, 2001.

[30] See, for example, ETC Group, "Genetic Pollution in Mexico's Center of Maize Diversity," Food First Backgrounder, Vol., 8, no. 2 (Spring 2002); E. Ortiz and J. Mainero, "Evidence of Gene Flow from Transgenic Maize to Local Varieties in Mexico," in *LMOS and the Environment: Proceedings of an International Conference*, OECD 2002, pp. 289-295, at http://www.oecd.org/document/18/0,2340,en_2649_34385_2509330_1_1_1_1,00.html.

[31] "StarLink found in more foods," United Press International, April 25, 2001; Paul Jacobs, "Banished biotech corn not gone yet," *San Jose Mercury News*, December 1, 2003.

[32] Sayer Ji, "Illegal StarLink GM Corn Resurfaces in Saudi Arabian Food Supply," *GreenMedInfo* August 16 2013, at http://www.greenmedinfo.com/blog/breaking-illegal-starlink%E2%84%A2-gm-corn-resurfaces-saudi-arabian-food-supply.

[33] Mary MacArthur, "Triple-Resistant Canola Weeds Found in Alberta," *Western Producer*, February 10, 2000, at http://www.producer.com/articles/20000210/news/20000210news01.html.

[34] L. Hall, et al., "Pollen flow between herbicide-resistant *Brassica Napus* is the cause of multiple-resistant *B. Napus* volunteers," *Weed Science*, Vol. 48, no. 6, pp. 688-694, November 2000.

[35] *GM Contamination Register Report* pp.15-19. Also Geoffrey Lean, "Rice contaminated by GM has been on sale for months," *The Independent*, August 27, 2006, at http://news.independent.co.uk/environment/article1222081.ece; Rick Weiss, "Rice Industry Troubled by Genetic Contamination," *Washington Post*, March 11, 2007

[36] Alan Bjerga and Jack Kaskey, "Rogue Oregon wheat stirs foes of Monsanto gene-altered crops," *Bloomberg Business Week*, May 30, 2013, at http://www.businessweek.com/news/2013-05-29/rogue-oregon-wheat-inflames-foes-of-monsanto-gene-altered-crops.

[37] "Bayer Settles With Farmers Over Modified Rice Seeds," *Bloomberg News*, July 1, 2011 (received via email).

[38] Justin Gillis, "Drug-Making Crops' Potential Hindered by Fear of Tainted Food," *Washington Post*, December 23, 2002.

[39] Editorial, "Drugs in crops - the unpalatable truth," *Nature Biotechnology*, Vol. 22 No. 2, p. 133, February 2004.

[40] "Genetic Traits Spread to Non-Engineered Papayas in Hawaii," Environment News Service, September 10, 2004.

[41] Sean Hao, "Papaya production taking a tumble," *Honolulu Adviser*, March 19, 2006; Alan D. McNarie, "Papaya Problems: Scientists square off over how safe Hawaii's genetically modified papaya is for consumers," *Hawaii Island Journal*, April 1, 2003, at http://hawaiiislandjournal.com.

[42] "GE papaya scandal in Thailand: Illegal GE seeds found in packages sold by Department of Agriculture," at http://www.greenpeace.org/news/details?item_id=547563; http://www.gmcontaminationregister.org.

[43] Lidia S. Watrud, *et al*., "Evidence for landscape-level, pollen-mediated gene flow from genetically modified creeping bentgrass with CP4 EPSPS as a marker," *Proceedings of the National Academy of Sciences, USA*, Vol. 101, No. 40, pp. 14533-14538 (October 5, 2004).

[44] Jay R. Reichman, *et al*., "Establishment of transgenic herbicide-resistant creeping bentgrass (Agrostis stolonifera L.) in nonagronomic habitats," *Molecular Ecology* Vol. 15, pp. 4243–4255 (2006).

[45] Andrew Pollack, "Modified Wheat is Discovered in Oregon," *New York Times*, May 30, 2013; Jack Kaskey, "Monsanto Resumed Field Trials of Roundup Ready Wheat," *Bloomberg News*, May 31, 2013, at http://www.bloomberg.com/news/2013-05-31/monsanto-resumed-field-trials-of-roundup-ready-wheat.html.

[46] Allison Snow, "Transgenic crops—why gene flow matters," *Nature Biotechnology* Vol. 20, p. 542 (June 2002).

[47] ETC Group Communiqué No. 102, "Who Will Feed Us? Questions for the Food and Climate Crises" (Ottawa: ETC Group, November 2009); Peter Rosset, "Fixing Our Global Food System: Food Sovereignty and Redistributive Land Reform," in F. Magdoff and B. Tokar, eds., *Agriculture and Food in Crisis: Conflict, Resistance, and Renewal*, (New York: Monthly Review Press, 2010); Miguel A. Altieri, "Agroecology, Small Farms, and Food Sovereignty," in Magdoff and Tokar, eds., *Agriculture and Food in Crisis*.

[48] Eija Pehu, "Biosafety Capacity Building: A World Bank Perspective," in M. A. Mclean, et al., eds., *A Framework for Biosafety Implementation: Report of a Meeting*," ISNAR (International Service for National Agricultural Research) Biotechnology Service, February 2003. For background, see B. Tokar, "The World Bank: Biotechnology and the 'Next Green Revolution'," in B. Tokar, ed., *Gene Traders*.

[49] Raj Patel, et al., "Ending Africa's Hunger," *The Nation*, September 2 2009.

[50] "Providing Proteins to the Poor: Genetically Engineered Potatoes vs. Amaranth and Pulses," New Delhi: Research Foundation for Science, Technology and Ecology, January 9, 2003, archived at http://www.gene.ch/genet.html.

[51] Aaron deGrassi, *Genetically Modified Crops and Sustainable Poverty Alleviation in Sub-Saharan Africa: An Assessment of Current Evidence*, Third World Network/Africa, June 2003, pp. 6-10.

[52] Gatonye Gathura, "GM technology fails local potatoes," Nairobi, Kenya: *The Daily Nation*, January 29, 2004, at http://www.nationaudio.com/News/DailyNation/Supplements/horizon/current/story290120041.htm.

[53] G.S. Mudur, "Cotton lessons for Bt brinjal," *The Telegraph* (New Delhi), February 15 2010; "Failure of Bt. Cotton in India" (New Delhi: Research Foundation for Science, Technology and Ecology, September 2002); "The Marketing of Bt Cotton in India" New Delhi: Greenpeace India and Centre for Sustainable Agriculture, September 2005); article archive from gaianet.org (via email), October 2002.

[54] Vivekananda Nemana, "In India, GM Crops Come at a High Price," *International Herald Tribune*, October 16, 2012; N. Gilbert, "Case Studies" (supra note 13).

[55] Devinder Sharma, "The Great Trade Robbery: World Hunger and the Myths of Industrial Agriculture," in B. Tokar, ed., *Gene Traders*.

[56] Michael Pollan, "The Great Yellow Hype," *New York Times Magazine*, March 4, 2001. Also Vandana Shiva, "Genetically Engineered 'Vitamin A Rice': A Blind Approach to Blindness Prevention," in B. Tokar, ed., *Redesigning Life?*

[57] Fabiola Ortiz, "Brazil develops 'superfoods' to combat hidden hunger," *The Guardian*, July 18, 2013.

[58] Fred Pearce, "An Ordinary Miracle," *New Scientist* Vol. 169 (February 3, 2001).

[59] Carol Kaesuk Yoon, "Simple Method Found to Increase Crop Yields Vastly," *New York Times*, August 22, 2000.

[60] John Vidal, "India's rice revolution," *The Observer* (UK), February 16, 2013; Jonathan Latham, "The Next Green Revolution (This Time Without Fossil Fuels)," *Solutions* Vol.4:2, June 4, 2013, at thesolutionsjournal.anu.edu.au.

[61] M. A. Altieri, "Agroecology, Small Farms, and Food Sovereignty" (*supra* note 47), p. 255.

[62] "Patenting the 'Climate Genes'... And Capturing the Climate Agenda" (Ottawa: ETC Group, May/June 2008; "Who will control the Green Economy?" ETC Group Communiqué no. 107 (Ottawa: ETC Group, November 2011).

[63] Doug Gurian-Sherman, "High and Dry: Why Genetic Engineering Is Not Solving Agriculture's Drought Problem in a Thirsty World" (Washington: Union of Concerned Scientists, June 2012); Tiffany Stecker, "Drought-Tolerant Corn Efforts Show Positive Early Results," *Scientific American*, July 27, 2012, at http://www.scientificamerican.com/article.cfm?id=drought-tolerant-corn-trials-show-positive-early-results.

[64] Beverly McIntyre, *et al*., *Synthesis Report: A synthesis of the global and sub-global IAASTD reports*, Washington, DC: International Assessment of Agricultural Knowledge, Science and Technology for Development Secretariat (2009).

[65] David Pimetel, *et al*., "Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems," *Bioscience* Vol. 55: 7 (July 2005), pp. 573-582.

[66] Catherine Badgley, *et al*., "Organic agriculture and the global food supply." *Renewable Agriculture and Food Systems* Vol. 22:2, pp. 86–108 (2007).

[67] M. Altieri, "Agroecology, Small Farms, and Food Sovereignty," p. 261.

[68] Adrian Muller and Joan S. Davis, "Reducing Global Warming: The potential of organic agriculture," Emmaus, PA: Rodale Institute (2009).