GMOs, Pesticide Use, and Alternatives

Lessons from the U.S. Experience

By:

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Two GM technologies now account for nearly all acreage planted to genetically engineered crop varieties worldwide – plants engineered to tolerate applications of broad-spectrum herbicides, especially glyphosate, and crops engineered to express the natural bioinsecticide, Bacillus thuringiensis, or *Bt*.

Herbicide tolerant crops account for about two-thirds of U.S. and global GM crop acres, *Bt*-transgenic varieties the remaining third.

Herbicide tolerant plants, particularly Roundup Ready soybeans, have been a commercial success (Fernandez-Cornejo, J., W.D. McBride, 2002; Benbrook, 2001a). This technology greatly simplifies weed management. In some areas, adoption rates are very high and in Argentina, approach 100 percent (Benbrook, 2002; Benbrook and Baumuller, 2003).

Impacts on Yields

None of the GM crops grown in the U.S. have been modified to increase inherent yield potential. GM crops have been modified to make pest management simpler and/or more effective. In the case of herbicide tolerant crops, application of a single broad-spectrum herbicide like glyphosate can make it easier to manage the full spectrum of weeds farmers routinely face. With *Bt* crops, the plants themselves produce a bacterial toxin that controls one, or a few insect pests.

University research in the U.S. has compared the yields of herbicide tolerant soybeans to otherwise identical varieties. Comparative yield trials are carefully designed and carried out in ways to identify any differences in yields under optimal growing conditions. Overall, the trials have shown a 4 percent to 8 percent yield drag (Opplinger et al., 1998; IANR, 2000; for a review of multiple studies, see Chapter on yield drag in Benbrook, 2001a).

Comparable yield trials on *Bt* corn and cotton have not demonstrated a statistically significant yield drag.

Roundup Ready Technology Impacts on Pesticide Use

Herbicide tolerant technology was designed to allow greater reliance on herbicides, not to decrease herbicide use. The technology works by allowing broad-spectrum herbicides to be applied on crops at times and in ways that were not possible before.

Herbicide tolerant technology could reduce herbicide use if it enabled a shift from herbicides applied at relatively high per acre rates (like glyphosate or atrazine, applied at 0.6

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to 1.0 pounds per acre), to a low dose herbicide, like those in the imidazolinone or sulfonylurea families of chemistry (applied at 0.01 to 0.2 pound per acre) (Benbrook, 2001). Table 1 provides an overview of soybean application rates in the U.S. in 2001, and shows the number of active ingredients applied at one-tenth or less the rate of glyphosate (total of nine), between one-tenth and about one-half the glyphosate rate (10 herbicides), from above the glyphosate rate to 1.0 pound per acre (2), and over 1.0 pounds (4). The table also shows the percent of acres treated with the market leader within the range and the chemical name of the leader. Glyphosate is included as a single value to aid in comparisons to lower and higher dose herbicides.

(Note to readers -- Several tables in this presentation are simplified versions of more complex tables. The complete version of such tables are posted for readers wishing more detail on the basis for various calculations or conclusions, access http://www.biotech-info.net/Pairs_Tables.html)

Table 1. Soybean Herbicide Application Rates in the U.S. (2001 USDA Data)

Application Rates (pounds per acre)	Number of Active Ingredients	Market Leader in Range	Market Leader Percent Acres Treated
0.0625 or less	9	imazethapyr	9%
0.063 – 0.325	10	fomesafen	7%
0.326 – 0.624	4	2,4-D	4%
0.625 – Glyphosate	**1**	**glyphosate**	**73%**
0.626 – 1.0	2	pendimethalin	10%
1.01 and over	4	sulfosate	3%
All Rates	**30**		
Percent < 0.326	**63%**		

Most herbicide tolerant cultivars are resistant to glyphosate, a relatively high dose herbicide, and hence the technology has not reduced herbicide use. Both my research and USDA studies show that there has been, on average, about a 5 percent increase in herbicide pounds applied per acre of GM soybeans in contrast to conventional varieties (Benbrook, 2001a and 2002; Fernandez-Cornejo, J., W.D. McBride, 2002).

The approximate quarter of U.S. farmers who switched to RR soybeans from weed management systems based largely on low-dose herbicides actually more than doubled the volume of herbicides applied per acre. A small number of farmers who shifted from high dose herbicide programs to RR soybeans marginally reduced the volume of herbicides applied per acre.

It is worth noting that farmers in Argentina planting Roundup Ready (RR) soybeans – and almost all do, using no-till -- have increased herbicide use substantially more than in the U.S. In 2000, farmers in the U.S. typically made about 1.3 applications on RR soybeans, farmers in Argentina made 2.3 applications (Benbrook, 2002). U.S. farmers applied an average 0.95 pounds of glyphosate per acre per year, while Argentinean farmers applied 2.47 pounds per year. Table 2 provides further detail, breaking down rates and use by tillage system.

Table 2. Extent of Adoption, Rates of Application and Use of Glyphosate in the Production of Roundup Ready Soybeans in the United States and Argentina: Crop Year 2000 Estimates

	Soybean Hectares Planted	Percent Hectares Planted to RR Soybeans	Glyphosate Active Ingredient: Number of Appli-cations	Glyphosate Active Ingredient: Average Rate of Application (Kilograms per Hectare)	Glyphosate Active Ingredient: Kilograms Applied	Glyphosate Active Ingredient: Pounds Applied
Conventional/ Conservation Tillage						
Argentina	3,096,000	75.0%	1.9	1.10	4,852,980	10,708,600
United States	19,732,029	52.0%	1.1	0.67	7,585,638	16,721,068
No-Till with Roundup Burndown						
Argentina	7,224,000	96.0%	2.5	1.20	20,805,120	45,890,061
United States	9,718,761	64.0%	2	0.78	9,754,207	21,501,258
All Tillage Systems						
Argentina	10,320,000	90.0%	2.3	1.20	25,634,880	56,653,085
United States	29,450,790	56.0%	1.3	0.76	16,330,907	38,685,976
Source: Benbrook, 2002a. See tables in Benbrook, 2002a for details of these estimates.						

Bt Transgenic Varieties and Insecticide Use

Bt-transgenic technology uses a natural plant toxin and a novel delivery system to mimic chemical-based pest management systems. In a given crop and region, the impacts of *Bt*-varieties on insecticide use are complex and changeable.

In the case of *Bt*-corn, USDA pesticide use data show that corn insecticide applications directly targeting the European corn borer (ECB) have risen from 4 percent of acres treated in 1995 to 5 percent in 2001, as shown in Table 3 (Benbrook, 2001c). In addition, several other insecticides are applied that control both the ECB and corn rootworm complex. A portion of these treated acres must therefore be counted as part of ECB-driven insecticide use. In Table 3, twenty-five percent of the “Multiple Pests” applications are counted as targeted to ECB control and another 50 percent to corn rootworms. Other insects account for the rest of insecticide use.

Table 3. Percent of U.S. National Corn Acres Treated with Insecticides by Target Pest

	1982	1991	1995	1998	1999	2000	2001
ECB Control	0.8	2.2	4.0	4.0	6.0	5.0	5.0
ECB: One Quarter of Acreage Treated for Multiple Pests	1.2	3.0	2.8	2.5	2.1	2.3	1.9
Total ECB Control	2.0	5.2	6.8	6.5	8.1	7.3	6.9
Total Rootworm Control	32.6	25.4	20.5	26.3	23.1	22.9	23.9
All Insects: Total Acres Treated	35.8	33.6	30.0	35.3	33.3	32.4	32.6

A total of about 6.9 percent of total U.S. corn acres were treated for ECB control in 2001, down from 8.1 percent in 1999, when *Bt* varieties first became widely available. Accordingly, the planting of about 25 percent of U.S. corn acres to *Bt* corn has reduced insecticide use about 2 percent of acres treated from its peak – not terribly impressive. Corn insecticide use targeting all insect pests has remained steady in the 1990s at about one-third of corn acres planted, as shown in the bottom line in Table 3.

Bt-cotton, on the other hand, has reduced insecticide use in several states. Prior to the introduction of *Bt* cotton, more than half cotton insecticide acre-treatments targeted the budworm-bollworm (BBW) complex of insects, the target of *Bt* cotton, as shown in Table 4. The average cotton acre received 2.12 acre-treatments with insecticides targeting the BBW complex in 1992. Reliance peaked in 1995 at just over 3 acre-treatments per acre and has fallen to just 0.77 in 2000, largely on account of *Bt* cotton (Fernandez-Cornejo, J., W.D. McBride, 2002). Note, however, that total cotton insecticide reliance, measured by acre-treatments, has changed little since the introduction of *Bt* cotton, evidence of changes in the insect community and shift away from broad-spectrum insecticides and toward more biologically-targeted chemicals.

In terms of pounds applied, insecticide use targeting the BBW complex has fallen from about one-half pound per acre in the early 1990s to 0.28 pounds per acre in 2000. Two factors clearly account for this large reduction – the boll weevil eradication program and second, *Bt* cotton, especially in the western U.S.

Cotton insecticide use trends must be studied carefully to accurately identify cause-effect relationships. The biggest reductions in bollworm-budworm complex insecticide use have occurred in the use of methyl parathion, profenofos, and thiodicarb. The former two are highly toxic organophosphates (OPs) that have triggered resistance problems and regulatory restrictions. As a result, most of the reduction in their use had occurred by the end of the 1996 season, prior to widespread use of *Bt*-cotton.

Table 4. National Cotton Insecticide Acre Treatments by Likely Pest Category

	1982	1995	1997	1998	1999	2000
Likely Target Pest						
Budworm/Bollworm Complex – Subtotal (millions)	21.382	35.428	17.253	13.965	11.362	11.144
Acre Treatments per planted acre	2.12	3.03	1.32	1.16	0.85	0.77
Multiple Pests – Subtotal (millions)	5.494	11.84	12.956	11.899	39.964	40.647
Acre Treatments per planted acre	0.54	1.01	0.99	0.99	3.0	2.82
Other – Subtotal (millions)	3.121	5.932	3.209	2.201	2.715	2.423
Acre Treatments per planted acre	0.31	0.51	0.25	0.18	0.2	0.17
Whitefly/Thrips – Subtotal (millions)	9.07	15.514	13.316	12.56	8.645	9.111
Acre Treatments per planted acre	0.9	1.33	1.02	1.05	0.65	0.63
All Insects -- Total	39.067	68.714	46.734	40.626	62.685	63.236
All Acre Treatments per planted acre	3.87	5.87	3.57	3.39	4.71	4.40

The impacts of resistance on cotton insect pest management around the world have been greater than in the case of any other crop-pest combination. This is a direct result of the heavy use of insecticides and the resulting intense selection pressure placed on populations.

Table 5 provides an overview of changes in cotton insecticide use since 1964. The big jump in OP use in 2000 was caused by large-scale eradication program spraying of malathion. Table 5 drives home the message that most families of chemistry last about than 10 years, based on how U.S. cotton farmers apply the products, before resistance leads to product failures and the search for new solutions.

The longevity of *Bt* cotton efficacy will be determined by the commitment and investment in Insect Resistance Management (IRM). Clearly, recent science confirms that well-designed and aggressively implemented IRM plans in *Bt* cotton can dramatically reduce selection pressure and delay resistance (Carriere et al., 2003). No one can predict with certainty, however, how long this will be the case. IRM planning and implementation has proven costly in the U.S., placing significant financial demands on public universities and growers. While focus on resistance management is a positive sign that farmers and the cotton growing community want to preserve the efficacy of *Bt* cotton, start-up and ongoing IRM costs nonetheless do need to be factored into cost-benefit equations. Thus far in the U.S. they have not been.

Table 5. Changes in Cotton Insecticide Use by Family of Chemistry (million pounds a.i.)

	1964	1966	1971	1976	1982	1992	1998	2000
Organochlorines	54.6	45.4	33	18.6	1.2	1.2	0.3	0.5
Organophosphates	15.6	14.3	28.6	31.4	12.9	13.4	11.3	36.1
Carbamates	6.2	4.5	10.3	12.2	3.5	4	2.7	3.5
Pyrethroids	0	0	0	0	0.8	0.9	0.4	0.3
Other	1.6	0.7	1.5	2	1	0.3	0.1	0.1
Total Pounds Applied	78	64.9	73.4	64.2	19.4	19.8	14.8	40.5
* Totals may not add due to rounding.								
Source: Calculated from USDA Chemical Use Surveys, multiple years.								

Economic Impacts

Net farm income has not been substantially impacted by GM crops in the U.S. (Fernandez-Cornejo, J., W.D. McBride, 2002; Duffy, 1999; Benbrook, 2001a, 2001c, 2002). The companies developing and patenting GM seed technologies have calculated the value of novel traits to farmers and set technology fees and/or seed premiums at levels approaching this value. Seed premiums and technology fees have been over $20.00 per acre for some GM cotton varieties, and are now about $8.00 per acre for Roundup Ready soybeans. The seed premium-tech fee likely to be imposed on Roundup Ready strawberries, if this technology reaches the market, has been projected at $150.00 per acre, reflecting the relatively higher cost of hand weeding in strawberries.

In general, the cost of GM seed has increased by about as much as pest management expenditures and/or the value of pest losses have fallen. Herbicide tolerant soybeans have been the one major exception and account for the most significant economic benefits to farmers (Fernandez-Cornejo, J., W.D. McBride, 2002). But the economic benefits from this technology have arisen from competitive pressures and price changes, not inherent efficiencies in the technology itself.

Since the introduction of Roundup Ready soybeans in 1996, manufacturers of soybean herbicides have reduced prices of soybean herbicides by nearly 50 percent across-the-board in an effort to slow their loss of marketshare (Benbrook, 2001a). Price cuts have been driven both by competition from Roundup Ready soybeans and the end of patent protection for glyphosate. Growers of both conventional and GM soybeans have been able to reduce herbicide expenditures during a period of generally increasing use.

When RR soybeans were introduced in 1996, the price of an acre-treatment with glyphosate at the recommended 0.7 pound rate was around $12.00. The end of patent protection for glyphosate in 2000 has opened the market to competitive products. In the 2002 season, many farmers purchased their glyphosate for about $7.00 per acre treatment. This year, glyphosate imported from China is reportedly available for about $3.50 a treatment, although the average cost of an acre-treatment will likely be around $5.00.

While glyphosate price reductions deliver short-term economic benefits to farmers, they also clearly increase the amount that farmers are willing to apply, in turn accelerating the emergence of resistant weeds (which have arrived, as discussed below)

In the case of *Bt* corn, some farmers have benefited, many others have not, and the net impact has been modestly negative. I carried out a detailed study of the economic impacts of *Bt* corn from 1996 through 2001 (Benbrook, 2001c). Details by year appear in Table 6. Over this six-year period, corn producers paid $659 million in price premiums for *Bt* corn varieties. Expenditures on *Bt* corn seed were 30 to 35 percent higher that otherwise well-adapted varieties – the largest increase in seed prices ever associated with a single added trait.

Expenditures on *Bt* corn paid off for farmers in three years (1996, 1997, 2001) because of relatively higher European corn borer pressure, yet resulted in losses in the other three years (1998, 1999, 2000).

On average over the six-year period, farmers harvested an estimated average 3.9 bushels more per acre planted to *Bt* corn, because of lessened damage from European corn borer feeding. Market prices during this period ranged between $1.82 and $2.71 per bushel, leading to a gross benefit of $567 million. Accordingly, over these six years corn farmers lost $92 million on their investment in *Bt* corn. In recent years, less *Bt* corn has been planted in areas in the eastern Cornbelt with low levels of ECB pressure, and more acreage is being planted in the southern and western edges of the Cornbelt, where insect pressure tends to be greater. These shifts will improve the economic performance of *Bt* corn from the farmers perspective.

Table 6. The Production and Economic Impacts of *Bt* Corn, 1996-2001: Bushels of Corn Yield Loss Avoided, Value of Increased Yield, the *Bt* Corn Premium, and Impact on Farm-level Profits, 1996-2001							
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**1996-2001 Totals**
Yield Loss Avoided (Bushels)	11,388,756	28,845,280	35,279,353	43,746,462	46,596,356	110,272,601	276,128,808
Dollar Value Added Yield	$ 30,863,529	$ 70,094,030	$ 68,441,944	$ 79,618,561	$ 86,203,258	$ 231,572,461	$ 566,793,785
***Bt* Corn Price Premium**	$ 11,690,000	$ 62,730,000	$ 144,720,000	$ 147,180,000	$ 154,250,000	$ 138,560,000	$ 659,130,000
Net Profit (Loss) from *Bt* Corn	$ 19,173,529	$ 7,364,030	$ (76,278,056)	$ (67,561,439)	$ (68,046,742)	$ 93,012,461	$ (92,336,215)
Source: Benbrook, 2001c.							

Sustainability of Herbicide Tolerant Technology

Herbicide tolerant technology has increased dependence on a single herbicide, glyphosate, to clearly unsustainable levels. The extent of use in the U.S. since about 1997 has triggered shifts in the composition of weed communities and set the stage for the emergence of resistant weeds (Harztler, 1999).

Excessive reliance on any single pest management tool heightens the selection pressure imposed on pest populations and sets in motion evolutionary processes that ultimately will undermine efficacy (Lewis et al., 1997). It is no surprise that Roundup resistant weeds have evolved in the U.S. and are beginning to force farmers to add additional herbicides to their weed management programs.

Earlier this month university scientists reported the first significant breakdown in the efficacy of Roundup Ready technology triggered by a resistant weed. The Associated Press covered the findings in a June 4, 2003 story, “Weed Could Cost Farmers Millions to Fight.” University of Arkansas weed management specialists are projecting that about 600,000 acres in the State will be infested with glyphosate resistant marestail (also known as horseweed) by next crop year. They estimate that farmers will have to spend an additional $8.00 to $15.00 per acre to control the resistant weeds in fields were they are present this year, and on much of the 600,000 acres next year and annually thereafter as long as Roundup Ready crops are planted.

The magnitude and severity of this problem in Arkansas reinforces the urgency of rethinking how RR technology is used, if the efficacy of glyphosate is to be preserved. In recent years in Arkansas, USDA pesticide use data show that about 3.5 million acres of soybeans have been grown, with about three-quarters planted to Roundup Ready varieties. About 970,000 acres are planted to cotton, with perhaps one-quarter Roundup Ready. Accordingly, Roundup Ready technology has been used on some 2.9 million acres annually for about four years, use that has led to a projected 600,000 acres infested with resistant horseweed. This is already about 20 percent of the 2.9 million acres on which Roundup Ready technology has been used.

Without aggressive measures to control resistant phenotypes, horseweed will spread throughout regions where Roundup crops are common. These measures will markedly increase both grower costs and herbicide use, reduce the acreage that can be planted to RR crops, and will have to be sustained for several years.

The rapid and already broad geographic spread of glyphosate resistant horseweed has occurred because of the intense selection pressure this weed has been subjected to in fields planted to Roundup Ready crops. This unfortunately proves correct the warning issued by many weed scientists that resistance would emerge as a much greater threat if glyphosate tolerance were engineered into agronomic crops and planted widely (Hartzler, 1999).

The longer-run impact of weed shifts and resistance on the viability of herbicide tolerant plants remains to be seen. Weed scientists in the U.S. generally agree that –

- The Roundup Ready system still works well in most places, although not as well as when it was first adopted.
- Resistance is appearing in weed populations somewhat more quickly than anticipated, based on glyphosate's long history of use without resistance prior to the introduction of HT technology.
- The pounds of herbicides applied per acre and cost of the RR system are edging upward, despite reductions in the cost of glyphosate, because of incrementally more serious weed shifts and resistance.

In addition, Roundup Ready soybeans have led to other ecological responses with negative consequences. For example, applications of glyphosate on RR Soybeans can retard root development and nitrogen fixation – adverse impacts worsened by drought (King et. al., 2001). Other examples are discussed in Benbrook (2001a).

Impacts on Biologically Based Pest Management Systems

Breeding crop varieties resistant to pest attack has been a dominant goal of plant breeders for centuries. There are many mechanisms plants use to defend themselves against pests. Some mechanisms entail producing chemicals that are natural pesticides (Seo et al., 2001; Verberne et al., 2000), a few of which have proven harmful to people or wildlife. Some of these natural chemicals are toxins that work as acute poisons like many conventional pesticides, while others work through more subtle and ecologically complex mechanisms. Non-toxic modes of action of natural chemicals include repelling pests, disrupting or discouraging their feeding or reproductive abilities, or sending out chemical signals that attract a pest's predators (Thaler, 1999).

In general and for obvious evolutionary reasons, the more direct and acutely lethal a pesticide's or natural chemical's impact on a pest population, the greater the likelihood that the pest will develop resistance to it. After all, if it does not, it may soon cease to exist as a species. Pests have a much more difficult time adapting to a natural chemical or pesticide that disrupts mating behaviour or morphological development, compared to a natural or synthetic toxin that simply has to be detoxified or avoided. Adapting to reproductive and behavioural challenges without reducing fitness typically requires a complex set of genetic adaptations in a population, while developing the capacity to detoxify or overcome a chemical toxin often requires nothing more than a single gene mutation.

This reality of pest management can be stated as a basic principle – the biological complexity of the mechanism used to disrupt a pest population impacts dramatically the evolutionary hurdles the population has to overcome in the face of ongoing selection pressure. This principle has profound implications for the sustainability and impacts of various applications of biotechnology.

Another way to state this point is that the impacts of any given GM technology on pest management systems will depend in large part on how the technology is designed to achieve its intended goal (Benbrook, 2003; Benbrook et al., 1996). Scientists working for the U.S. Department of Agriculture (USDA) have pointed out that delivering lethal doses of a natural toxin like *Bt* through plant tissues will lead to many of the same problems as chemical sprays (Lewis et al., 1997). In a key 1997 paper in the *Proceedings of the National Academy of Scientists*, the USDA scientists state:

> "The use of therapeutic tools, whether biological, chemical, or physical, as the primary means of controlling pests rather than as occasional supplements to natural regulators to bring them into acceptable bounds violates fundamental unifying principles and cannot be sustainable."

In addressing emerging applications of biotechnology to pest management, they argue that:

> "As spectacular and exciting as biotechnology is, its breakthroughs have tended to delay our shift to long term, ecologically based pest management because the rapid array of new products provide a sense of security just as did synthetic pesticides at the time of their discovery in the 1940s….The manipulated pathogens and the crops engineered to express toxins of pathogens are simply targeted as replacements for synthetic pesticides and will become ineffective in the same way pesticides have. It will be unfortunate if these powerful agents are wasted rather than integrated as key parts of sustainable pest management systems."

Bt technology is prone to trouble both because of its simple mechanism and because of how pests are exposed to the *Bt* toxins in transgenic plant tissues. Lewis et al. point out that *Bt* technology "…amounts to a continuous spraying of an entire plant with the toxin, except the application is from the inside out." (Lewis et al., 1997). Such continuous exposure obviously increases and extends selection pressure.

More Complex Strategies Needed for Sustainable Progress

Consider an alternative tactic and technology in the breeding of plants with the ability to withstand pest pressure. Plants under attach by caterpillars and other sucking or chewing insects sometimes send out a chemical signal – a plea for help, in fact – that attracks parasitoids. Jasmonic acid is one of these chemical signals. Increasing the expression of jasmonic acid has been shown to more efficiently attract parasitoids, that in turn lessen insect feeding damage (Thaler, 1999; De Moraes et al., 1998). This approach would be consistent with the basic complexity principle stated above and would likely prove more stable.

Many other examples can be cited of radical differences between simple biotechnology approaches now under development by the private sector, in contrast to more complex systems interventions receiving at best modest attention from a few publicly funded research organizations. One of the best examples entails how to tap into and enhance a plant's innate ability to withstand plant pathogens.

Many teams are working to genetically engineer plants to augment systemic acquired resistance (SAR), the plant's generic immune response to many pathogens. In 1997 a team based at the University of California-Berkeley described the role of the NDR1 gene in controlling SAR (Century et al., 1997), an important breakthrough that dramatically increased research interest and funding. Several teams have since been pursuing what is sometimes called the "master switch" for plant defence mechanisms (e.g., Verberne et al., 2000; Alibhai and Stallings, 2001).

Most of the new research money for combating plant disease invested in the U.S. by the public and private sector has gone to work on triggering or reinforcing SAR via genetic modification. Other approaches have largely been ignored, including some that appear more promising in the long-run, particularly to meet the needs of developing world farmers. For example, field research in China in 1998-1999 produced dramatic and encouraging results through an approach to disease management called intraspecific crop diversification (Zhu et al., 2000). Rice fields in five townships were planted to a mixture of rice cultivars that were susceptible and resistant to rice blast disease, the region's major pathogen. Yields rose 89 percent and blast severity fell 94 percent in the fields planted to seed mixtures compared to monoculture controls. The authors note that:

> "…it is significant that the diversification program described here is being conducted in a cropping system with grain yields approaching 10 Mg ha^{-1}, among the highest in the world. The value of diversity for disease control is well established experimentally and diversity is increasingly being used against wind-dispersed pathogens of small grain cereals."

In the future, low-cost and effective disease management strategies in some row and grain crops may depend largely on the planting of diverse mixtures of cultivars. The tools of biotechnology, especially marker assisted breeding, may play a supportive role in making this strategy feasible by helping produce varieties that yield compatible grain that grows and matures in unison, allowing efficient harvest.

This strategy, where plant breeders focus on relatively modest changes in cultivars to be mixed together, to then better exploit an existing, ecosystem-based pathogen control mechanism, is consistent with the conditions needed for pest management sustainability. It is also striking how different this approach is conceptually and in terms of costs and risks compared to ongoing efforts to trigger or reinforce SAR through transgenic modification.

A Perspective on the Safety of GM Foods Now on the Market

There are several reasons why food safety concerns remain over GMO crops and food. Biotech promoters and the U.S. government are correct in saying there is no evidence of serious harm to Americans who have consumed GMO corn or soybeans; biotech critics and scientific sceptics are equally correct in saying that the science base supporting a judgement of safety for GM foods is based on too much wishful thinking and too little science. The WTO case may or may not help bridge these conflicting views.

All of the GM food technologies now on the market were approved by the U.S. government on the basis of a policy decision that they were "*substantially equivalent*" in terms of composition (solids, sugars, etc), protein content, lipid profiles, and macro- and micro-nutrient profiles. For all intents and purposes, there were no animal or human food safety assessments requested or done if these simple tests of composition equivalency were satisfied.

The U.S. government position was and remains that such assessments were unnecessary. Many scientists, however, are more conservative. To them, potential food safety concerns lurk in the unintended impacts of genetic transformation on plants, the stability of gene expression in transformed plants, and how GM plants interact with their environment. Responses of GM cultivars to combinations of biotic and abiotic stresses, in particular, strikes many scientists as literally and figuratively a "wild card."

Most of the reassuring commentary from the U.S., such as "*...all Americans have been eating this food for years and are fine...*" is misleading and in an important way, not relevant. GM corn and soybeans are mostly processed and fed to animals: very small volumes are consumed directly by people in relatively unprocessed forms. Essentially zero research has been done on impacts of GM food on pregnant women, infants, and children - the population groups likely to be most vulnerable to adverse impacts, if there indeed are any. It will take large, expensive and sophisticated epidemiological investigations to determine whether people and farm animals (or pets) are, or are not suffering allergic reactions or other problems. These studies have not been undertaken in the U.S. or elsewhere, to my knowledge. Hence, extrapolating from the "*lack of evidence of harm*" in the U.S. to other countries, cultures, and circumstances where GM food might be consumed differently (for example, in the form of food aid, largely unprocessed, and as a major component of the diet) is basing safety assurances on assumptions, some of which are based on other assumptions.

Many scientific societies on both sides of the Atlantic, and a few in cyberspace, have been asked to look at the issue of GM food safety. When asked if there is evidence of harm, the answer is generally cautiously reassuring. Unfortunately, most reviews do not delve more deeply into the unresolved issues of food safety. The lack of pertinent data to review is one major reason why. Those few scientific assessments that have done so with the benefit of current literature in peer reviewed journals rarely dismiss all concerns and almost always recommend additional public sector research to settle lingering issues. The U.S. position that the current absence of evidence of GM food safety risks is now ample proof of safety, versus the view in Europe that more science should be done before reaching safety judgements that open the whole food supply to GM transformation, will be one of the major debates in the WTO case and the scientific community for the next decade or so.

Comments on GM Food Aid

Developments in Zambia last summer set in motion what has become a far-reaching, high-decibel global debate about the role of GMOs in food aid, and more broadly, over the possible contributions of biotechnology in meeting food security needs in developing countries.

Surprisingly, the U.S. government and biotech advocates have prominently featured the growing opposition among many developing countries to GM crops and food aid as one of the major reasons why the U.S. has initiated a WTO case against the EU. As far as I can tell, three important points have been largely absent from this dimension of the GMO-food safety debate.

First, when the companies advanced *Bt* corn through the regulatory process in the U.S. and Europe, it was known and understood that 98 percent plus of the corn would be fed to animals or processed. If regulatory authorities believed that a sizable share of the American consumers eating *Bt* corn would consume it directly and that, moreover, the corn might make up as much as half or two-thirds of daily caloric intake, they would NOT have approved it based on the data presented at the time. Anyone who claims that U.S. regulatory reviews of *Bt* corn technologies in the early 1990s "proves" safety in the context of food aid to Africa is either unaware of the nuances of risk assessment science or poorly informed of the scientific basis of U.S. regulatory reviews at that time.

Second, people in Africa who are suffering acute or chronic malnutrition, AIDs, and/or other health problems may react to consumption of *Bt* corn - especially when minimally cooked and processed, and present as a major share of their diet - in different ways than the average American or European has reacted to it. It is known that *Bt* corn may have adverse impacts on the stomach lining, and that potential food safety/allergenicity impacts are impacted in many ways by gut bacteria and the overall health of the gastro-intestinal tract. It is doubtful that any company or government institution has carried out the research needed to determine whether these differences could translate into risks in Africa among the very hungry that are both qualitatively and quantitatively distinct from those that might be expected in North America and Europe.

Third, food aid can and has had negative impacts on farm prices and production in recipient countries. Solving short-run food insecurity crises in a region by undermining the people and the economic sector that must deliver food security in the long-run strikes many people as less than satisfying. Food aid can both meet the pressing needs of the hungry and build agricultural capacity and support infrastructure development when food aid is provided in cash and used to buy basic foodstuffs in the region. The U.S. could easily switch its current policy of providing food aid in the form of grain (whether GM or not), by selling grain stocks on the market and transferring the cash proceeds in the form of aid.

Of course, such a change in U.S. policy will have some costs associated with it, and will increase the need for accountability regarding how aid funds are spent, but many reputable NGOs can handle the money and purchasing, as they are successfully doing in several countries with food aid cash donations from the EU. This approach would also put an end to conspiratorial assertions that the U.S. is trying to force GM food on poor countries.

Providing *Bt* corn food aid to hungry people in Africa is certainly better than starvation, if the only near-term option. But shouldn't the world community step back and ask why GM food aid became, for even a short period, the only option?

This question is not uppermost in the minds of U.S. commodity groups and politicians praising the Bush Administration for filing the WTO case. In introducing a Senate resolution urging the President to aggressively pursue the WTO case and raise GM food issues at the June G-8 summit, Senator Bill Talent said –

> "To me, the turning point was when the European Union countries not only refused to take the biotech product themselves, which I don't even think is defensible, but then they began trying to convince African countries that are in danger of famine to turn down shipments of safe, nutritious U.S. humanitarian biotech food aid." (Floor statement, U.S. Senate, May 23, 2003)

The WTO Case

The May 13, 2003 filing of the United States WTO case against the European Union's moratorium on GM foods is likely to lead to unintended consequences on both sides of the Atlantic. This step has set in motion a process that will –

- Raise the stakes in ongoing confrontations between the U.S. and EU over genetically engineering, trade, developmental assistance, and agricultural policy.
- Provide the U.S. and the EU an important new forum in which to debate the safety and environmental impacts of GM crops.
- Receive substantial media coverage and attention from all sides of the debate and the general public.
- Impact in a variety of ways the attitudes of consumers, the food industry, regulators, and politicians all over the world.

The WTO case will trigger a broadening of scientific and public debate in the U.S. over the costs, benefits, and risks of GM food and agricultural biotechnology. This broadening of debate is long-overdo and will hopefully prove constructive in the long-run. Most Europeans are unaware that there has been little independent, open scientific focus on the safety and benefits of GM foods in the United States. There has been countless days and millions of person-hours spent by dozens of groups discussing what sort of risk assessment science and policies are needed, but no consensus has yet been reached and very little independent risk assessment research has been done.

In the late-1980s, then Vice-President Dan Quayle led a "Council on Competitiveness" composed of senior political appointees from several agencies. Its mission was to identify hot areas of science and technology where the U.S. might gain a stronger position in international markets through innovation. Biotechnology was among those chosen to promote, a decision that led to several key policies in the late 1980s and early 1990s – substantial equivalence, the coordinated framework, no need for basic safety research.

In the current climate, the U.S. agricultural biotechnology regulatory system and policy framework is both difficult to augment and improve as new challenges emerge (without acknowledging weakness), and difficult to defend as thorough and rigorous relative to contemporary scientific understanding and international food safety norms and testing recommendations.

Another practical reality has limited open, scientific debate on GM food technology in the United States. With exception of those working for or on behalf of the biotechnology industry, very few scientists have had access to company data on GM crop transgenes, the methods used to transform plants, where and how transgenes are expressed, and the stability and expression of transgenes as impacted by biotic and abiotic stresses.

Indeed, I know of not a single independent scientist in the U.S. that has gained access to such data on any current GM crop or food. Furthermore, I am near-certain that no independent scientist or laboratory has received the funding, information, and technical cooperation required to carry out what any team of experts would consider a thorough and independent assessment of GM food safety claims.

A recent Washington Post article (May 30, 2003) on the GM food approval process in the U.S. makes clear that not even government regulatory scientists see full data packages or have access to the same information as the companies seeking approvals:

> "The FDA reviews biotech foods for safety, and the agency's action on a new biotech crop is often characterized in press accounts as approval. But legally, it isn't.
>
> "The FDA operates a voluntary system under which biotech companies decide on their own how to test the safety of their products, submit summaries of their data -- not the full data -- to the FDA, and win a letter that says, in so many words, that the agency has reviewed the company's conclusion that its new products are safe and has no further questions. In most cases, the data on which the safety conclusion is based remain secret. It is a much less rigorous system than the FDA procedures for reviewing new drugs or food additives, in which the agency will spend months if not years going over company claims in detail."

The adequacy of past U.S. government reviews of GM food technologies will surely be a part of the WTO case, as will an open-ended assessment of environmental impacts. Already, a series of U.S. National Academy of Sciences (NAS) reports since 2000 have recommended steps needed to improve the scientific foundation for GM food related food safety and environmental risk judgments. Anyone can compare side-by-side the scientific studies and rigor called for in recent NAS or contemporary Codex recommendations for the evaluation of GM food safety risks, in contrast to the science-base supporting today's GM foods. The conclusions drawn will be obvious, although many people will continue to argue that the preponderance of evidence, and the U.S. experience, proves that GM foods pose no meaningful or measurable food safety risks. I sincerely hope they are proven correct.

Current policies are beginning to change in all three U.S. agencies with important GM-related responsibilities – the FDA, EPA, and USDA. Each agency has extensive new "draft" or "proposed" regulatory requirements in various stages of evolution, but a long process lies ahead for all of the agencies, likely to take many months to several years, before any major substantive changes are made in core data requirements or decision-rules. Full implementation of new regulatory policies that will reliably deliver credible, modern, and rigorous safety assessments are years away.

The filing of the WTO case is likely to slow the pace of change in U.S. policies, since it will be difficult for the Bush Administration to defend policies before the WTO as fully adequate at the same time the policies are being reformed in response to recommendations from the NAS and other scientific advisory boards. Some of the changes can and will be attributed accurately to better knowledge and scientific advance, but a major portion of the changes under review are filling gaps in current regulatory reviews.

The U.S. and Europe together face a daunting scientific challenge in gaining a fuller understanding of the impacts of GM food technology in the diversity of ecosystems and circumstances in which they may be, and are being deployed. The big difference, or course, is that the U.S. has forged ahead with approvals and widespread commercial adoption, while the EU has moved more slowly. Several hundred million of dollars in annual U.S.-EU agricultural export trade that is "in play" with the WTO case is making it difficult for the U.S and the EU to find a mutually acceptable way to bridge this difference.

One thing is certain – much time, energy, and political capital will be devoted on both sides of the Atlantic to the task of bridge building. The road ahead will be long and difficult because there will be vastly differing views on the kind of bridge needed, and those dissatisfied with the leading design may devote their energy to assuring no bridge is ever completed.

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